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EXPERIMENT DESIGN MANUAL AND HAZARDS ANALYSIS - PLUM BROOK REACTOR FACILITY

EXPT. NO. 63-05

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PREFACE

This document is a combined design manual and hazards analysis for an in-pile water-cooled capsule in the HT-1 tube of the Plum Brook Reactor Facility (PBRF). This manual is submitted in accordance with requirements of PBRF letter XSP-1002-R2, "Preparation of Experiment Design Manual and Hazards Analysis", January 24, 1964.

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1.0 INTRODUCTION

1.1 EXPERIMENT OBJECTIVES

The basic purpose of the experimental system described and evaluated in this report is to provide information which will assist in the selection of materials and components for incorporation in the NRX (NERVA Reactor Experiment) currently being designed by Westinghouse Astronuclear Laboratory.

There is at present insufficient information on the performance of many items in the high radiation environment which is required in the NRX system. A water-cooled capsule has been designed and installed in HT-1 at PBRF for testing the required items in a high radiation environment.

The dose rate in HT-1 is considered the closest available to the actual NRX levels, and a primary consideration is that many of the radiation effects which are of importance are those associated with dose rate rather than total integrated dose.

1.2 EXPERIMENTAL FACILITY

This is a loop-type facility which provides the capability for test-instrument actuation and data acquisition. The facility consists of an inpile water-cooled capsule, associated piping, and handling equipment, and is located in Quadrant C of PBRF. The capsule is installed from the Quadrant C side of HT-1. The items to be tested are contained in the water-cooled capsule.

1.3 TEST ASSEMBLIES

Some types of test assemblies to be irradiated are pressure transducers, strain gages, linear displacement transducers, resistance thermometers, accelerometers, and various mechanical components. Westinghouse Drawing 566F393 shows a typical test assembly specifically designed for strain gage testing. Since the nuclear and thermal characteristics of all conceivable test assemblies cannot be predicted, the approach in this report has been to analyze the system assuming certain "envelope" values for one typical experiment. These values are:

Total Weight	9 lb
Outside Diameter	6.12 inch
Length	6.5 inch

2.0 PROCESS DESIGN

2.1 SYSTEM OBJECTIVES AND DESCRIPTION

The objective of the coolant system is to remove the heat generated in the materials exposed to the neutron and gamma field existing in HT-1. The critical objective of the design is to provide cooling in a manner such that surface temperatures will not only be controlled under any mode of operation but also may be reasonably well predicted.

2.1.1 Normal Sample Cooling Arrangement

The following drawings illustrate the piping system:

Engineering Flow Diagram	566F394
Piping Arrangement	709J932
Orifice Plate and Pipe Support Details and Assembly	576F013
Reach Rod and Guide Plate Details and Assembly	576F014
Instrument Tubing Arrangement	576F015
Equipment Mounting Modifications	PF-S-12865
Piping Modifications	PF-S-12866

The normal sample cooling arrangement described below is applicable during that time from the completion of the system instrumented checks described in Section 6.2 through the period of reactor power operation, to the initiation of the sample changing procedure outlined in Section 6.3. Refer to Dwg. No. 566F394. The main flow path is shown by the heavy line.

In a normal cooling operation, cooling water enters HT-1 at the Quadrant A end through a 3-inch pipe line. The coolant flows through HT-1, encounters the capsule head and continues down the annular gap between HT-1 and the capsule, emerging from a 2-inch nozzle located on the bottom of the adapter sleeve. Beyond the nozzle flange a 3-inch by 2-inch reducer is used to regain the nominal 3-inch pipe size. Coolant flows in the 3-inch line, through a second 3-inch by 2-inch concentric reducer located downstream of the capsule bypass connection, through the capsule inlet valve, PC-V1, and into a length of 2-inch I.D. metal flex hose to the sample holder. Flow proceeds down the sample holder, past the sample fixture and into the interior of the capsule. After a 180° turn, the coolant flows away from the core, interior to the capsule but outside the sample holder. The coolant leaves the capsule through a nozzle to which a second length of metal hose is flanged, proceeds through a capsule outlet valve, PC-V2, the system check valve, PC-V3, a third 3-inch by 2-inch concentric reducer and into a 3-inch line flanged to the existing 3-inch PCWR Header No. 3.

When the capsule is not in HT-1, the normal coolant flow will enter HT-1 at the Quadrant A end, pass down HT-1 and out the adapter sleeve nozzle in Quadrant C. The capsule inlet and outlet globe valves, PC-V1 and PC-V2, will be closed while the 3-inch capsule bypass gate valve, PC-V4, will be open. Flow will be through the bypass valve, the 3-inch bypass line and into the main return line downstream of the 3-inch by 2-inch reducer.

The available coolant flow rate, with the capsule inlet and outlet valves full open is greater than the design (experiment) flow rate due to the PBR change from 1.5-inch to 3-inch pipe. The "wide open" flow rate prior to full-power reactor operation was found to be in excess of 100 gpm. During the experimental run, the flow rate is reduced to the normal operating rate of 75 gpm. This is done by throttling the capsule outlet valve PC-V2. (The capsule bypass valve, PC-V4, will <u>not</u> be used in any way during normal operation. It will remain closed). When the capsule is not in HT-1, flow will be controlled by PBRF valve 29V13.

2.2 DESIGN CRITERIA

Design in all cases conforms to applicable portions of Sections 1 and 8 of the ASME Boiler and Pressure Vessel Code and the Code for Pressure Piping, ASA B31.1. Where the codes do not cover materials or designs incorporated in the system, the normal code safety factor of 4 and a generally conservative approach have been taken.

Design data are listed in Table 2.1. The process parameters for the system design are: the total heat generation rate, the water mass flow rate, the inlet water temperature, the "no boiling" requirement reflected in a 300°F capsule-surface temperature limitation, the coolant cross-sectional flow area, and the thermal conductivity of the materials in which the heat is generated and from which it must be removed. Of these parameters, only the last two may be varied in order to meet the surface temperature limitation, the first three parameters being fixed by the existing reactor operating conditions.

2.2.1 Heat Generation Rate

The design is based on total heat generation measurements in HT-1. A straight line approximation of the heating rate was developed and is discussed in Section 7 of this manual.

Table 2.1

Design Data for Normal Operation

Capsule Flow Rate	75 gpm
HT-1 Inlet Temperature	135°F
Coolant Exit Temperature	153.6°F
Design Metal Temperature	300°F
Maximum Operating Capsule Wall Temperature	188.2°F
Maximum Operating Pressure (Capsule External Pressure)	160 psia
Hydrostatic Test Pressure (External Pressure)	207 psig
Peak Gamma Heating Rate at 60 Mw Reactor Power	8 watts/g
Maximum Capsule Differential Pressure	138 psi

2.2.2 Coolant Mass Flow

Coolant for the HT-1 tube (and thus, coolant for the experiment) flows in parallel with the primary coolant through the reactor vessel. Hence, a given reactor coolant flow will cause a corresponding flow through the HT-1 circuit. At normal reactor flow, the pressure drop available to force coolant through the HT-1 circuit has been measured at approximately 53 psi. In the existing 3-inch HT-1 circuit, this pressure drop results in a flow rate in excess of 100 gpm.

2.2.3 Inlet Water Temperature

Although the PBR inlet water temperature is 125°F, a design HT-1 inlet water temperature of 135°F has been chosen. This is a conservative value.

2.2.4 Coolant Cross-Sectional Flow Area

The cross-sectional flow area into which the greatest amount of heat is dumped is the annular gap between HT-1 and the capsule. The flow area here is a nominal 1/4-inch annulus extending outward from the 8.50-inch O.D. capsule to the 9.00 inch I.D. of HT-1. The geometry of sample holder, capsule and HT-1 is generally that of concentric annular flow areas. Heat transfer coefficient calculations, found in Section 7.1 have therefore been based on the following equation (from McAdams' third edition of Heat Transmission,[1] p. 242, which is written in the abbreviated form using the symbols delineated on page 135):

$$(N_{St})_b \; (N_{Pr})_b^{\;2/3} \left(\frac{\mu_w}{\mu_b}\right)^{0.14} = 0.023 \; (N_{Re})^{-0.2}$$

where "b" refers to the bulk coolant temperature and the Reynolds Number is computed using the equivalent diameter, $D_e = D_o - D_1$.

2.2.5 Materials

In the proximity of the core, all equipment is aluminum. The sample fixture is aluminum as far as practicable. Sample materials are based on NERVA requirements, hence, are not subject to the in-pile capsule design. Aluminum is chosen for its high thermal conductivity relatively short-lived impurity activation products and compatibility with existing equipment. Away from the core, all equipment is low carbon, austenitic stainless steel - chosen primarily for corrosion resistance, strength and compatibility with existing piping. Transitions from the one material to the other are clearly noted on final drawings.

2.2.6 Design Utility Requirements

Table 2.2

Utility Requirements

Utility	Use	Flow Rate (gpm)	Inlet Temp (°F)	Outlet Temp (°F)
Primary Coolant	Experiment Cooling	75	135	153.6
Deionized Water	Purge to Hot Drain (intermittent)	Variable	90	120 Max.
Waste Helium (Total quantity per experiment, maximum 220 SCF)	Transducer Actuation	0.10 SCFM (Approx.) Intermittent	200 Max.	
Deionized Water	Emergency Cooling	Variable	90	200 Max.

Utility	Use	Power	Volts	Frequency	Phase
Electrical	Instrument Panel Power	1 Kw	110 V	60 cycle	1 ϕ

2.2.7 System Instrumentation

Process measurements consist of inlet and outlet flow, water pressure, water temperature, and experiment temperature, all discussed in Section 4.

Both flow measurements are made using standard orifice plates located in the 3-inch Schedule 10 pipe. The HT-1 inlet flow measuring orifice is located in a straight run of pipe 4-feet long, leading to the Quadrant A end of HT-1. The outlet flow orifice is installed in a 5-feet long straight run of 3-inch Schedule 10 pipe parallel to the wall between Quadrants B and C.

The pressure tap for the pressure recorder is located in the length of line parallel to the wall between Quadrant B and C that extends from the adapter sleeve to the prefabricated piping section. As a result, the pressure reading reflects a water pressure slightly lower than that in the HT-1 to capsule annular gap and slightly greater than the water pressure at the sample fixture. The pressure tap for the water pressure indicator, PI-1, is located just upstream of the flanged connection between the prefabricated piping and the flexible hose connected to the sample holder. This set-up provides a means of monitoring water pressure (hence leakage) during the capsule hydro-test.

The HT-1 inlet water thermocouple (TE-1) is located downstream of the inlet orifice plate and near the end of the 4-feet spool piece. Thermocouple TE-2 is located adjacent to the water pressure tap and indicates a water temperature slightly less than the actual HT-1 outlet temperature and slightly greater than the sample holder inlet temperature. (Since the piping is located under water in Quadrant C, the coolant will lose some heat to the quadrant water). The same situation will exist for TE-3 which is located just downstream of the flange connecting the capsule outlet flexible hose to the prefabricated piping section.

2.2.8 System Auxiliaries

Water is provided for purging and emergency cooling, at a nominal pressure of 80 psig and a temperature of 90°F, through connections to the existing 1.5-inch deionized water headers in both Quadrant A and C.

The sample holder, sample fixture, and interior of the capsule are purged of primary coolant prior to sample changing, by opening the purge valve, P-V1 and using the capsule drain valve, VD-V1 to throttle flow through the capsule and out into the hot drain header. Prior to removing the capsule from HT-1, the through-tube is purged of primary coolant using the existing PBR system of piping and valves, i.e., opening PB15V33 in Quadrant A and using PB20V67 to throttle purge flow to the hot drain.

Deionized water is also used as a source of emergency coolant, should such coolant be required. For example, if the flexible hose connected to the sample holder should rupture, primary coolant would contaminate the quadrant water and the cooling flow to the sample fixture would cease. The operator would open the capsule by-pass valve and close the capsule inlet and outlet valves. Coolant flow in the capsule-to-HT-1 annular gap would thus continue, the integrity of the primary coolant system would be regained, and only the volume of primary coolant between the inlet and outlet valves would be available to contaminate the quadrant water. To provide cooling to the sample fixture, the operator would open the emergency coolant valve, EC-V2. When the water pressure in the capsule had decreased to approximately 80 psia, deionized water would flow into the capsule outlet line via the check valve, EC-V1. Flow would proceed backwards to the normal sample cooling path and out the rupture into the quadrant. This method can be used for a rupture in the inlet flex hose. In the event of a leak in the outlet hose, the purge valve P-V1 and capsule drain valve, VD-V1, could be used in a manner similar to purge operations in order to get sufficient cooling flow.

Vent connections are provided on both the adapter sleeve, for HT-1, and the capsule. Water overpressure relief as required by the Code is provided by PC-V5.

2.3 SAMPLE DESCRIPTION

2.3.1 A Typical Experiment

The gas system for a typical experiment such as the strain gage experiment is shown in Drawing No. 566F394. Gas is supplied from a standard cylinder via a two-stage pressure regulator and a three-way valve to a small accumulator or charge bottle, which serves as the source of gas used to pressurize the bellows. Gas is addmitted stepwise in small quantities by cracking and then closing the gas supply needle valve, SA-1, the gas pressure being raised in steps of about 50 psi. Stainless steel tubing and flexible all metal hose (1/4 inch I.D.) are used to conduct the gas from the accumulator to the "trace" connection on the flange of the sample holder. The sample holder is made of Alcoa Unitrace with the "trace" flow area being used to conduct the helium to the sample fixture. The "product" flow area of the Unitrace is used to conduct the cooling water to the sample fixture.

The gas pressure is normally kept slightly below the water pressure preventing the possibility of a gas leak into the water. However, in the strain gage experiment, full deflection of the beams requires a pressure increase of about 125 psi and a resulting maximum gas pressure of about 265 psia. The beam is returned to the zero point by exhausting the helium via the gas outlet needle valve, SA-V3, to the radiation-monitored reactor tank vent system. A length of 2-inch pipe is supported along the wall between Quadrants B and C at an elevation of 11-1/2 ft. This pipe connects the existing flange of the vent system to the 1/4-inch exhaust tubing. Overpressure relief for the bellows, hose and tubing is provided by the gas safety valve, SA-V4. A valved-off (SA-V2) vacuum connection is provided to initially evacuate the gas system of air prior to filling the system with helium.

2.3.2 Design and Operating Safety Features

Several design features and the operating procedures are specifically intended to prevent leakage of helium into the primary coolant.

The manually-operated three-way valve provides a mechanical interlock preventing direct connection of the gas cylinder to the bellows. Hence, if a major rupture of the supply system were to occur, only the volume of gas in the accumulator, 1/4-inch tubing, 1/4-inch flexible hose, and sample holder would be available to leak into the primary coolant (for a flexible hose rupture, gas would leak into the quadrant water).

The accumulator is sized at 70 cubic inches and has a design pressure of 300 psig. The purpose of the accumulator is to avoid a direct connection between the high-pressure helium supply and the system. The helium must pass through a 1/32-inch diameter restriction orifice in order to reach the interior of a bellows. The orifice prevents the full pressure of the gas from being applied to the interior of the capsule in the event of a bellows leak.

2.4 SYSTEM SETPOINT LIST

Parameter	Condition	Normal Operation	Alarm Set Point	Scram	Instrument
Inlet Flow	Low	3.26 ma (75 gpm)	2.70 ma (65 gpm)	-	Optical Meter (FS-1b)
Inlet Flow	Low-Low	3.26 ma (75 gpm)	2.00 ma (50 gpm)	2.00 ma (50 gpm)	Monitor Switches (FS-3 or FS-4)
Outlet Flow	Low	3.26 ma (75 gpm)	2.70 ma (65 gpm)	-	Optical Meter (FS-2b)
Outlet Flow	Low-Low	3.26 ma (75 gpm)	2.00 ma (50 gpm)	2.00 ma (50 gpm)	Monitor Switches (FS-5 or FS-6)
System and Exp. Temp.	High	Variable up to 140°F	250°F	-	Multipoint Recorder Switch (TRS-1)
System Pressure	Low	2.90 ma (143 psig)	2.47 ma (110 psig)	-	Optical Meter (PS-1b)
Exp. Temp.	High	Variable up to 140°F	4.3 ma (250°F)	-	Optical Meter (TS-2a)

3.0 EQUIPMENT DESCRIPTION

3.1 GENERAL

Equipment for the experimental cooling system may be divided into three major categories: capsule ensemble; capsule handling equipment; pipe, valves and piping components. A summary of the inspection and test procedures for equipment which was fabricated specifically for the experiment is included in Appendix B. The Equipment List is shown in Appendix C. The following drawings are concerned with system equipment:

Capsule Ensemble

Sample Holder Details and Assembly	709J928
HT-1 Adapter Details and Assembly	709J929
General Arrangement (Capsule)	709J930
Capsule Assembly	709J931
Capsule Details and Sub-Assembly (Al)	566F386
Capsule Details and Sub-Assembly (S.S.)	566F387
Junction Box, Cap and Back Plate Details	566F391
Junction Box Gasket Details	386D716
Clamp Assembly	386D719
Guide Assembly	387D518

Handling Equipment

Support Structure Details and Assembly	566F395
General Arrangement (Quadrant C)	566F400
Lifting Bar Details and Assembly	576F011

Piping

Piping Arrangement	709J932
Orifice Plate and Pipe Support Details and Assembly	576F013
Reach Rod and Guide Plate Details and Assembly	576F014
Instrument Tubing Arrangement	576F015
Equipment Mounting Modifications	PF-S-12865
Piping Modifications	PF-S-12866

3.2 CAPSULE ENSEMBLE (Dwg. 709J930)

The in-pile capsule is designed for the purpose of subjecting a test sample within its confines to nuclear irradiation. The capsule is inserted into the HT-1 facility of the PBRF.

Primary coolant of the reactor will be circulated through the capsule to remove heat generated in the interior of the capsule. The capsule will be placed in the test hole at the beginning of a reactor cycle and removed when the reactor is shut down. The capsule is designed for the following conditions:

External Pressure Difference	138 psi
Maximum Operating Temperature	300°F

The capsule ensemble includes the sample holder, the capsule, the capsule guide assembly, the HT-1 adapter sleeve, and two Marman flange clamps.

Material certificates are provided on all materials incorporated in the capsule ensemble. All welds are dye-penetrant inspected and all pressure or containment welds are also radiographed. A hydrostatic test to 150 percent of design pressure, as specified in the ASME Code, has been performed by the vendor on the completed assembly.

A spectrochemical analysis of the aluminum of the type used in construction of the capsule is given in Appendix B.

A general arrangement of the capsule assembly is illustrated in Drawing 709J930 and the individual parts are detailed in the drawings as noted in Section 3.1.

3.2.1 Sample Holder

The sample holder is basically a length of nominal 2-inch Alcoa Unitrace (or equal) used to center and support the sample fixture within the capsule and provide a means of introducing coolant directly to the sample fixture. Unitrace is used, rather than standard 2-inch pipe, to provide a more compact and easily cooled assembly of coolant supply and sample actuating gas lines. In addition, the "trace" flow area could be used in some experiments, as a dry access line for transducer extension leads.

The sample fixture is welded to the in-core end of the sample holder. Two guide rings, spaced 3-ft. apart, support and center the sample fixture within the capsule. Possible hot spots at guide ring-capsule wall interfaces are essentially eliminated by locating the closest guide ring 3-ft. from the core midplane. The guide rings are welded to the Unitrace.

The back plate assembly (Drawing 566F391) provides a pressure-tight closure between the aluminum Unitrace and the stainless steel end of the capsule. The back plate assembly is made up of two basic parts: an aluminum transition plate welded to the aluminum Unitrace, and a stainless steel back plate bolted to the transition plate. A Flexitallic gasket between the two plates prevents leakage of primary coolant out the annular gap between the Unitrace and the stainless back plate. The transition plate supports and centers the out-of-core end of the sample holder in the capsule and aligns the back plate flange, relative to the flange on the capsule.

The back plate is the structural member, resisting the primary coolant-to-quadrant water pressure difference. The back plate outer diameter was made the same as the outer diameter of the capsule flange, so that the two Marman flange clamps can be used at either location. A rubber (Buna N) gasket, retained on the back plate by the transition plate, seals the capsule-to-sample holder flanged joint.

To change samples, the flanged joint between the sample holder and flexible hose is made up and broken non-remotely, above the quadrant water surface. A 90° inside-traced elbow is used to remove the flanges from any direct neutron beam and permit easier disassembly with the sample holder in a vertical position.

3.2.2 Capsule

The capsule is basically an 8.50-inch O.D. by 11.5-ft length of pipe with a hemispherical cap butt-welded to the in-core end. Its nominal 5/16-inch wall thickness is based on an external pressure of 160 psi at 300°F (for aluminum 6061-T6). The sole purpose of the capsule is to provide the flow barrier required in the three-pass, single-coolant design.

Two lifting eyes centered on the horizontal centerline are located on opposite sides of the capsule and are provided for handling and insertion purposes as discussed in Section 3.3.

Two 2-inch Schedule 40 nozzles centered on the vertical capsule centerline and located at the top and bottom of the capsule provide, respectively: the capsule vent connection, and the capsule outlet water connection. Both nozzles terminate in 2-inch, 150-lb R.F. welding neck flanges of 304L stainless steel. The upper nozzle contains a 2-inch by 2-inch by 3/4-inch reducing tee for purposes of attaching a Conax fitting for the capsule thermocouple sheathed extension leads. Upon removal of these thermocouples, the Conax fitting was plugged and seal welded.

When the capsule is not inserted in HT-1, a blank cap, shown on Drawing 709J930 and detailed on Drawing 566F391, is inserted into the adapter sleeve to provide a pressure-tight gasketed closure of HT-1.

In-Core End - The in-core end of the capsule is fabricated from 8.50-inch O.D. aluminum 6061-T6 seamless tubing, the proper wall thickness being established by boring out the thinner wall. The aluminum section of the capsule (Drawing 566F386) is butt-welded to an aluminum-to-stainless steel transition joint located about 8 ft from the core midplane.

Out-of-Core End - Butt-welded to the stainless steel end of the transition joint is the 304L stainless steel out-of-core end of the capsule (Drawing 566F387). Although the stainless steel end need not have as thick a wall as the aluminum, the same I.D. is maintained over the length of the capsule to facilitate movement of the sample holder guide rings.

Transition Joint - The aluminum to stainless steel transition is a brazed type of lap joint which has been recommended for the water-cooled capsule application. The joint is made by coating the steel pipe with aluminum and brazing the aluminum pipe to the aluminum-coated steel pipe. Data is available on one such joint that has been physically tested with satisfactory results. Refer to Appendix B for details of the test procedure and results.

Flanges - Two flanges designed for use with Marman flange clamps (Drawing 386D719) mate with flanges on the adapter sleeve and the sample holder back plate. The flanges are identical in O.D. and slope of the wedging surface.

A rubber (Buna N) gasket is used for the pressure-tight closure to the adapter sleeve. The enlarged O.D. of the capsule, directly in front of this flange, is provided to center and support the capsule within the adapter sleeve and provide proper flange alignment.

3.2.3 Adapter Sleeve (Drawing 709J929)

The purpose of the adapter sleeve is to simplify the problem of making and breaking a pressure-tight joint remotely under 21 ft of water. The adapter sleeve is constructed from a 1-1/2 ft length of nominal 10-inch Schedule 40, 304L stainless steel seamless pipe. Welded to the near-core end of the sleeve is a 1.5-inch thick slip-on flange which bolts to the existing flange on HT-1. A 20-inch diameter S.S. plate is installed between the adapter flange and the HT-1 flange resulting in an arrangement similar to a flanged orifice plate joint. In order to accommodate non-perpendicularities between flanges and tube centerlines, the plate is thinner at the bottom than at the top. As shown on the drawing, the centerlines of the 10-inch pipe and the flange bolt circle are offset by 1.594 inch. Two lifting eyes are provided on the horizontal centerline of the sleeve for handling and capsule insertion purposes. Two nozzles, one 2-inch and one 1-inch located on the vertical sleeve centerline, provide HT-1 vent and HT-1 coolant outlet connections. Both nozzles terminate in 150 lb R.F. welding neck flanges. A flange designed to mate with and be clamped to the capsule flange by a Marman flange clamp is butt-welded to the out-of-core end of the sleeve. The bore of this flange mates with the enlarged capsule diameter located just in front of the capsule flange, providing support and centering of the out-of-core section of the capsule.

3.2.4 Capsule Guide Assembly (Drawing 387D518)

A guide assembly bolted to the bottom inside surface of the adapter flange protrudes into and lies on the bottom quadrant of HT-1. The guide assembly centers and supports the capsule within HT-1, maintaining the 1/4-inch annular gap between the capsule and HT-1 and preventing wear of HT-1 by the capsule. The assembly consists of two guide strips located at 45° from the vertical centerline of HT-1 and attached at both ends and in the middle by circular segments. The strips are 1/4-inch diameter rods extending in to a point 3 ft from the core midplane. The in-core ends of the strips are connected by a 90° segment about 3/32-inch thick. The out-of-core ends of the strips are connected by a 90° segment which is bolted into the adapter flange.

3.2.5 Flange Clamps (Drawing 386D719)

The two flange clamps are identical. The clamp design is a standard Marman design modified slightly for application to the water-cooled capsule design. The clamp is made up of four segments which surround the circumference of the flanges. The four segments are constructed of 304L stainless steel and are connected together by two stainless steel straps riveted to the segments. The straps are connected at each end to trunnions which ride up and down on two vertical threaded shafts.

The clamp is operated from above the quadrant water surface by using a long-handled tool fitted with a hex head socket wrench. First one and then the other of the two shafts are turned, tightening the straps and wedging the four segments down onto the flanges. The segments are positively driven together and apart by the movement of the trunnions up and down the shafts.

3.3 CAPSULE HANDLING EQUIPMENT

The equipment includes a capsule dolly, a capsule stand, a lifting bar and attached cable, various nylon ropes, and miscellaneous long-handled tools. The existing PBR 20-ton polar crane will also be used. The equipment is shown in plan and elevation on Drawing 566F400 and detailed in the drawings noted.

3.3.1 Capsule Dolly (Dwg. 566F395)

The dolly is essentially a wheeled support clamped to the capsule between the capsule-adapter sleeve flange and the two nozzles. Its purpose is to provide a movable support for the capsule and to provide vertical alignment of the capsule with HT-1. All materials are aluminum 6061-T6 or 303 stainless steel. The support legs and cross braces are 1-inch O.D. by 0.25-inch wall aluminum tubing, welded construction. Unidirectional casters running in tracks bolted to the quadrant floor provide capsule rolling support. Plates 1/2-inch thick are provided for vertical adjustment in initial installation. Two 2-inch wide by 1/3-inch thick straps wrap over the top of the capsule and are bolted down to a support pad.

Tracks are provided for two-directional alignment of the capsule and HT-1. The tracks are shown on Drawing PF-S-12865. They extend out 13 ft from the leading edge of the adapter sleeve. The tracks may be adjusted vertically by movement of the sliding wedges. The tracks are constructed from channels, the sides of which provide guidance with sufficient play to prevent binding.

3.3.2 Capsule Stand (Dwg. 566F395)

The capsule stand is a welded support structure made of one-inch O.D. by 1/4-inch wall aluminum tubing. Its purpose is to support the capsule, in conjunction with the capsule dolly, for in-quadrant capsule storage purposes. The stand has 4-inch square flat pads attached to the four support legs to provide a stable, non-moving support. The top of the stand is dished to prevent the capsule from sliding, or being easily pushed off the stand.

3.3.3 Lifting Bar (Dwg. 566F011)

The lifting bar is a welded 6061-T6 aluminum assembly constructed from standard structural shapes and plates. The lifting bar is used to hold the capsule in a horizontal position during insertion and withdrawal from HT-1. The lifting bar is supported by a 1/4-inch diameter stainless steel braided wire cable attached to a chain fall which is supported from the hook of the 20-ton polar crane.

4.0 INSTRUMENTATION AND CONTROL

4.1 SYSTEM DESCRIPTION (Drawings: Westinghouse No. 566F394, 386D718,

There are no automatic devices to control the experiment, except for the automatic action of the instrumentation system to scram the reactor as a result of either "low-low" inlet flow or "low-low" outlet flow. The instrumentation is listed in Appendix D, and a description of functions is provided in Section 4.2. Instrument setpoints are listed in Section 2.4. Each piece of instrumentation is separately fused and has a "power available" light.

4.1.1 Flow Instrumentation

There are two similar but independent instrumented flow channels: One channel monitors flow entering HT-1, the other monitors flow leaving the 63-05 facility. Differences in recorded flow rates, other than calibration errors, would indicate leakage of primary coolant. Instruments for the two channels are similar except for sensor location. Flow is measured using orifice plates and differential pressure transmitters. Independent power supplies provide d-c power to the two transmitters. At zero flow and consequent zero-differential pressure, the transmitters send a 1 ma signal to the appropriate channel of a two channel miniature strip chart indicating recorder. At 100% flow (100 gpm) the orifice plates develop a (calculated) differential pressure of 50-inches of water. The transmitters produce a 5 ma signal under this differential pressure.

Each flow-channel has a two-level alarm system. Normal flow is 75 gpm. An alarm is actuated at low flow (65 gpm) and an alarm and reactor scram are initiated at low-low flow (50 gpm). The two alarm systems are again independent of each other but similar in characteristics and functions. (Alarms may occur, then, for inlet low flow, outlet low flow, inlet low-low flow and outlet low-low flow. Reactor scrams accompany both inlet and outlet low-low flow alarms.)

Separate instruments are used to produce the low flow alarm signal and the low-low flow alarm and scram signal within each flow-channel. For a given channel, the differential pressure transmitter supplies the same milliampere signal to the recorder and each of the instruments, causing the low and low-low flow alarms. The two low flow alarm signals (inlet and outlet flow) originate in optical meter-relays upon receipt of a milliampere signal equal to or thermocouples measuring sample fixture temperatures are also connected to the multipoint recorder.

The multipoint recorder produces a stamped chart record, and can record up to 24 points, but generally has been used as an 8 point recorder. The recorder receives millivolt signals from the thermocouples. Loss of this millivolt signal causes the print wheel carriage to drive full scale. A limit switch is located on the recorder at a point corresponding to 250°F on the temperature indicator scale. Upon a high temperature signal or a loss of signal, the print wheel carriage trips the limit switch, actuating a relay. Actuation of the relay causes a local audible-visible high temperature alarm on the 63-05 console and a remote alarm on the XCR summary alarm unit.

A fourth thermocouple measuring sample fixture temperature is the sensing element for the second temperature channel. This thermocouple sends a millivolt signal to an EMF/I converter (temperature transmitter) which changes the millivolt signal to a milliampere signal. The milliampere signal is sent to the temperature channel of the two-channel miniature strip chart indicating recorder.

The milliampere signal from the EMF/I converter also goes to a two setpoint optical meter-relay. (Only the lower setpoint is used.) On high temperature (250°F) the optical meter actuates a relay located in an alarm module. Actuation of the relay causes a local high temperature audible-visible alarm on the 63-05 console and a remote alarm on the XCR summary alarm unit.

4.1.3 Pressure Instrumentation

There are two pressure channels. One consists simply of a local pressure gage for hydrotesting and checking the other pressure channel. The instrumented pressure channel consists of a power supply which reads d-c power to a static water pressure transmitter. The transmitter sends a milliampere signal to the pressure channel of the two channel recorder described in Section 4.2.

The pressure transmitter sends the same signal to a two setpoint optical meter-relay. (Only the upper setpoint is used.) The optical meter controls a relay via a control module. Upon low pressure (110 psig) the relay causes a local audible-visible low pressure alarm at the 63-05 console and a remote alarm on the XCR summary alarm unit.

4.2.8 Inlet Flow Power Supply - Furnishes d-c power to the inlet flow differential pressure transmitter.

4.2.9 Outlet Flow Power Supply - Furnishes d-c power to the outlet flow differential pressure transmitter.

4.2.10 Pressure Power Supply - Furnishes d-c power to the pressure transmitter.

4.2.11 Inlet Flow Optical Meter - Causes a signal to be sent to the appropriate channel of the local audible-visible alarm unit and the XCR summation alarm unit upon receiving a milliampere signal corresponding to the low flow setpoint. Only meter setpoint "b" is used.

4.2.12 Outlet Flow Optical Meter - Causes a signal to be sent to the appropriate channel of the local audible-visible alarm unit and the XCR summation alarm unit upon receiving a milliampere signal corresponding to the low flow setpoint. Only meter setpoint "b" is used.

4.2.13 Pressure Optical Meter - Causes a signal to be sent to the appropriate channel of the local audible-visible alarm unit and the XCR summation alarm unit upon receiving a milliampere signal corresponding to the low pressure setpoint. Only meter setpoint "b" is used.

4.2.14 Temperature Optical Meter - Causes a signal to be sent to the appropriate channel of the local audible-visible alarm unit and the XCR summation alarm unit upon receiving a milliampere signal corresponding to the high temperature setpoint. Only meter setpoint "a" is used.

4.2.15 Limit Switch - Causes a signal to be sent to the appropriate channel of the local audible-visible alarm unit and the XCR summation alarm unit, upon being mechanically actuated by the multipoint temperature recorder drive carriage at the setpoint temperature.

4.2.16 Inlet Flow Monitor Switch - Is current-sensitive, and causes a signal to be sent to the appropriate channel of the local audible-visible alarm unit and the XCR shutdown panel for reactor scram, upon receipt of a milliampere signal from the inlet flow transmitter, corresponding to the low-low flow setpoint. Two identical monitor switches are series-connected in order to increase the degree of fail-safety. Either of the two switches can cause a reactor scram independently of the other switch.

5.0 HAZARDOUS MATERIALS

No potentially hazardous material will be utilized in this experiment.

The lifting bar assembly is about 8 ft long with 2 ft long "L" shaped arms extending downward at each end of the bar, forming a cradle in which the capsule or sample holder rests. Several holes drilled along the length of the bar provide adjustment in the point at which the lifting cable can be attached, allowing for longitudinal variation in the center of gravity of the item being lifted. The arm farthest from the core is designed to accept the greater O.D. of the capsule flange and use the flange as a mechanical stop.

3.3.4 Long-Handled Tools

Long-handled tools are required for a number of capsule handling and general operations purposes: operation of the Marman clamps; handling the sample holder in Quadrant C, Canal E, Canal F, Canal-Area 18; handling the capsule in Quadrant C.

The system of nylon ropes and pulleys is used to insert and withdraw the capsule from HT-1, as discussed in Section 6.

3.4 PIPING SYSTEM

The piping system consists of the normal complement of pipe, fittings, flanges, valves and valve reach rods, instrument tubing, pressure, temperature and flow rate sensors, as shown mainly on Drawings 566F394 and 709J932, and noted in the Equipment List.

The piping system is primarily a butt-welded (ASME qualified) seamless Schedule 10 system incorporating 1, 1-1/2, 2, and 3 inch piping and valves. A 4-ft long section of 3-inch pipe, in which the HT-1 inlet flow orifice plate (with attached instrument tubing) and the inlet water temperature thermocouple are located, is the only piping provided in Quadrant A. All instrument tubing is 1/4-inch O.D. by .049 inch wall 304 S.S.

In Quadrant C, the piping system may be considered in two sections:

(1) A prefabricated and hydrotested section contains the main process valves, and is built up from a rectangular piping support plate, which rests on and is attached to the quadrant floor. Its major axis is parallel to the wall between Quadrants B and C and it is located so that the valve reach rod closest to the core just clears the lily pad. Four process lines are involved: the adapter sleeve outlet; the capsule outlet returning water to the primary coolant system; a deionized water line providing water for both purge and emergency cooling; and a hot drain line. The four lines are provided with flanges at the break point of the prefabricated section. The two 2-inch I.D. flexible metal hoses lie on the quadrant floor and connect the prefabricated section to the capsule ensemble.

(2) A section of piping is fabricated in place which contains no valves or instrument connections, and which connects the prefabricated section to existing process lines (i.e., PCWR, DW, HD). The piping generally runs southward from the northwest corner of the quadrant across the circular face of the reactor shield wall to the wall separating Quadrants B and C (the existing headers end in the northwest corner). From there the piping runs parallel to the wall down to the prefabricated section.

3.4.1 Valves and Piping Components

The main process valves are 150 lb, 304 S.S., globe valves O.S. & Y. bolted bonnet with socket welded ends for 2 inch and smaller, and butt-welded ends for 3 inch. The valves are Aloyco Fig. No. 314 and Pacific Fig. No. 702 and 1102 (swing check).* Instrument valves are 1/4-inch 304 S.S. Imperial needle valves. The process valves have permanently attached reach rods made from 1-1/4 inch O.D. Schedule 80, 6061-T6 aluminum pipe. The handwheels can all be operated by a person standing on top of the wall between Quadrants B and C. The reach rods are guided by a plate attached to the quadrant wall at 0 ft, 0 inch elevation.

3.4.2 Pipe Fittings

Pipe fittings are all Schedule 10, 304 L S.S. seamless butt-welded fittings. Flanges are 150 lb slip-on RF 304 L S.S. flanges. The orifice flanges are 300 lb RF 304 L S.S.

* Refer to the Aloyco and Pacific Stainless Steel Valve Catalogues.

3.5 SAMPLE EQUIPMENT

Equipment for a typical experiment, for example the strain gage test, can be divided into two groups: gas system equipment and fixture equipment. The following drawings concern the sample equipment.

Gas System Equipment

Piping Arrangement	709J932
Engineering Flow Diagram	566F394

Strain Gage Fixture Equipment

Sample Fixture Body Assembly	566F392
Sample Fixture General Arrangement	566F393
Sample Fixture Details and Sub-Assembly	566F408

3.5.1 Gas System Equipment

Gas system equipment consists of the following: 1/4-inch O.D. 304 stainless steel tubing, 1/4-inch I.D. flexible all-metal hose made of 316 stainless steel, and having a pressure rating equivalent to Schedule 40 pipe and 2-inch Schedule 10 304L stainless steel pipe; 1/4-inch 304 S.S. needle valves, a three-way 1/4-inch manually operated valve and a 1/4-inch 304 stainless steel gas safety valve set at 300 psig; an accumulator made from a 1-1/2 ft length of 2-inch Schedule 40 304 S.S. pipe and 2 pipe caps, and a (200 Std ft^3) helium cylinder; a pressure gage and a two-stage helium pressure regulator.

The gas cylinder constitutes the gas supply. The pressure regulator reduces the 2200 psi cylinder gas pressure to the accumulator delivery pressure of 300 psig. The three-way valve is used as a mechanical interlock prohibiting direct connection of the gas cylinder to the bellows. The accumulator is used as a source of gas to pressurize the bellows. The needle valves are used as control valves to admit helium, exhaust helium and establish the initial evacuation of the system. The relief valve is used to protect the bellows and flexible hose against overpressure. The pressure gage has a range of 0 - 400 psig with 10 psi divisions on the scale. It is used to monitor the gas pressure at the bellows in order to keep the proper relation between water and gas pressures and to provide in this particular system, a correlation between gas pressure and strain gage output.

All of the items mentioned above except the gas cylinder and pressure regulator are mounted on a panel board attached to the side of the system instrument panel. The 1/4-inch tubing is used to connect the items mentioned. The gas cylinder is located next to the experiment rack with the pressure regulator mounted on the cylinder.

The instrument panel sits over a hole in the floor at "0-0" elevation. The 1/4 inch gas supply and exhaust tubing lines are routed through this hole and then through a rectangular slot in the curved quadrant back wall. The lines extend down the wall to elevation 11 ft, 6 inches, and then horizontally along the wall to the wall between Quadrants B and C. The lines run along the latter wall to a point just east of the reach rod guide plate. The 1/4 inch exhaust line connects to the 2 inch exhaust line at this point. The supply line extends down the wall to elevation 24 ft, 6 inches, and connects there to the 1/4 inch I.D. flexible hose extending to the sample holder.

3.5.2 Typical Experiment Fixture Description (Strain Gage Fixture)

The following is a description of a typical experiment fixture - that used for the strain gage experiment. The strain gage fixture houses the eight pairs of strain gages, the two resistance temperature detectors and the six thermocouples which comprise the samples to be tested in this experiment. Eight strain gages are the Budd bonded type, and eight are weldable gages made by Microdot. The platinum resistance thermometers are made by Winsco and the copper-constantan thermocouples are made by Pyroelectric.

Other major items of the fixture are: eight beams to which strain gages are attached; eight bellows which deflect the beams causing the measured strain; the zero and maximum beam deflection stops; the gas tubing line and distribution block; the inner coolant flow shroud; and the outer shroud and coolant outlet nozzle. The rest of the fixture constitutes the supporting structure.

The fixture is constructed of 6061-T6 aluminum with 2024-T4 aluminum fasteners, except for strain gage beams, gas tubes to bellows, bellows retention bars, butt-weld male tubing connector, distribution block -- all 304L S.S.: and bellows -- 316 S.S.

The maximum-deflection beam stop is provided to give an identifiable end point to the experiment, i.e., increased gas pressure results in no further deflection, hence no greater strain measurement. The zero-deflection beam stop is provided to give assurance that the beam always returns to the same zero point. The zero point stop is set at a position which gives a slight deflection of the beam with the fixture in air and 0 psig internal gas pressure. The slight deflection insures that the beam always returns positively to the stop and provides no measuring problem since the test measurements are only relative to the zero stop measurement.

The gas tubing line connects the "trace" flow area of the Unitrace to the distribution block. The bellows retention bar provides assurance that the bellows cannot slip off the beam due to the dynamic forces exerted by the coolant. The distribution block or mainfold provides passageways for the gas to the bellows. A 1/32 inch diameter orifice restricts the possible flow under the maximum gas-to-water differential pressure.

The inner coolant flow shroud is provided to direct flow outward to the annular volume where the major mass of metal is located. The outer shroud provides a smooth surface for the coolant flowing away from the core. The outlet nozzle is provided to direct flow at the center of the hemispherical head, insuring sufficient cooling to that critical point.

less than that corresponding to 65 gpm (i.e., 0-2.7 ma). The meter-relays have two adjustable setpoints but only the upper one is used. The optical meters control relays in the annunciator circuit.

The actuation of these relays causes an audible and visible alarm at the 63-05 console, and an audible and visible alarm on the 63-05 summary alarm unit in XCR. On the 63-05 console, separate alarm lights are provided for the inlet and outlet low (and low-low) flow alarms. The horn is common to all console alarms.

The two low-low flow alarm (and scram) signals originate in current-sensitive monitor switches upon receipt of a milliampere signal equal to or less than that corresponding to 50 gpm (i.e., 0-1.95 ma). The monitor switches have an adjustable setpoint. To increase the degree of fail-safety, two independent monitor switches are provided in both the inlet and outlet flow channels. In both channels, the two monitor switches are series-connected such that either switch can independently cause an alarm and scram. Either of the pair of monitor switches in a flow channel can control a relay. Actuation of this relay causes initiation of an (audible-visible) low-low flow and alarm on the 63-05 console, and production of a scram signal to the XCR Shutdown Panel. This scram signal then goes to a scram light and reactor control system in RCR.

In order to check the capability of each of the four monitor switches to cause a reactor scram, a DPDT test switch and pair of indicating lights is provided in each flow channel. The test switch is connected in parallel with the series-connected monitor switches. One monitor switch is bypassed and the other put on test, for either "On" position of a test switch. (The flow is throttled to 50 gpm or less to check scram production for each test switch position.) Pushing the test switch to either of its positions will actuate an indicating light. The light is labeled to indicate which monitor switch is on test and which one is bypassed for a particular test switch position. The test switches are spring loaded to return to the center "Off" position.

4.1.2 Temperature Instrumentation

There are two instrumented temperature channels; one uses a multipoint recorder, the other, a strip chart recorder.

Thermocouples measuring system water temperatures are installed at HT-1 inlet, HT-1 outlet, and capsule outlet. Two grounded hot junction, copper-constantan thermocouples are installed at each of the above locations and are connected to the multipoint recorder in parallel. Generally, three

4.1.4 Remote Alarms

A 63-05 summary alarm unit (audible-visible) is installed in the XCR. The unit is actuated in the event of any 63-05 alarm condition except low-low flow. The low-low flow signal from the 63-05 console actuates a relay and alarm light on the XCR shutdown panel. The scram signal is then transmitted to an alarm light and the reactor control system in the RCR.

4.2 INSTRUMENT FUNCTIONS

Listed below are brief descriptions of the functions of each item of instrumentation. Refer also to the Instrument List, Appendix D, for characteristics of each item.

4.2.1 Flow Recorder - Records both the inlet and outlet flow rates on a single strip chart.

4.2.2 Pressure/Temperature Recorder - Records on a single strip chart the nominal system water pressure and an incore experiment water or metal temperature.

4.2.3 Multipoint Temperature Recorder - Records on a stamped chart the following temperatures: HT-1 Inlet, HT-1 Outlet, Capsule Outlet and up to 21 additional experiment temperatures. The recorder drives upscale upon loss of input signal.

4.2.4 Inlet Flow Differential Pressure Transmitter - Sends a single milliampere signal to the inlet flow optical meter, the inlet flow channel of the flow recorder, and the two series-connected monitoring switches for inlet flow.

4.2.5 Outlet Flow Differential Pressure Transmitter - Sends a single milliampere signal to the outlet flow optical meter, the outlet flow channel of the flow recorder, and the two series-connected monitoring switches for outlet flow.

4.2.6 Pressure Transmitter - Sends a single milliampere signal to the water pressure optical meter and the water pressure channel of the pressure/temperature recorder.

4.2.7 Temperature Transmitter (EMF/I Transmitter) - Converts a millivolt signal from a copper-constantan experiment thermocouple to a milliampere signal sent to the experiment temperature optical meter, and the temperature channel of the pressure/temperature recorder.

4.2.17 Outlet Flow Monitor Switch - Same as inlet flow monitor switch. Receives signal from outlet flow transmitter. Causes scram and actuation of appropriate channel of the local audible-visible alarm unit. Again, two identical monitor switches are series-connected for the outlet flow channel.

4.2.18 Pressure Indicator - Provides local (not panel mounted) water pressure indication for hydrotesting and check of pressure recorder.

4.2.19 Annunciator - Local audible-visible eight channel alarm unit. Upon actuation of a channel, the corresponding light flashes on and off and the horn is actuated. These alarms continue until the "Acknowledge" push button is depressed. Alarm acknowledgement stops the horn and changes the light from flashing to a steady "On" condition. The light goes off automatically when the alarm condition is removed. The annunciator also has a lamp test push button.

4.3 INSTRUMENT INSPECTION AND MAINTENANCE

Prior to and during the initial installation of the 63-05 experiment console, all equipment was checked out for calibration. Test results are recorded in Westinghouse Test Record Book No. 17443, pp. 1744300-9. Routine calibrations and inspections of the 63-05 experiment console are performed in accordance with the manufacturers' instruction manual listed below.

Manual	No.
1. L & N	177090
2. L & N	177097
3. L & N	177093
4. Minneapolis Honeywell	334-0
5. Daystrom	6704
6. SCAM	SC-AC/SC-BC
7. Westinghouse Exp. (Alarm Module)	63-05

6.0 OPERATIONS

6.1 GENERAL

The operations for the water-cooled experiment system may be divided into pre-irradiation handling and testing, operation, and post-irradiation handling. Most testing and calibration of system instruments and the sample equipment are conducted in the pre-irradiation period. The more critical handling operations are performed in the post-irradiation period, following activation of the items. This section summarizes the operational steps necessary to perform the experiment.

6.2 STARTING CONDITIONS

The reactor is shutdown, and Quadrant C is filled with water. The Quadrant A HT-1 experiment will have been removed and HT-1 purged with deionized water. The sample holder with sample fixture attached will have satisfactorily passed bench tests for proper transducer operation. All 63-05 system maintenance and instrument calibration will have been completed. For a new experiment, the sample holder reactivity worth will have been determined directly or shown by calculation to be less significant than in previous experiments. (The fual need not be removed from the core prior to inserting or removing the capsule and/or sample holder.)

6.3 PRE-IRRADIATION PROCEDURES

6.3.1 Handling

The adapter sleeve flange clamp is loosened and the blank cap removed, permitting free interchange of water in HT-1 and the quadrant. The lifting bar is attached to the chain fall supported from the polar crane and used to lift the capsule off the capsule stand, move it over, and set it down with the dolly wheels on the tracks. (A long-handled hook is used to guide the capsule down into position). The capsule is moved forward, along the tracks, with force being exerted by both the long-handled tool and a set of ropes. The two ropes are attached by shackles and hook to the lifting eyes on the capsule and are routed through pulleys attached to the lifting eyes on the adapter sleeve. After the capsule hemispherical head has passed the in-core end of the adapter sleeve, the capsule will be supported and centered by the two guide strips. At this point, the lifting bar is disengaged from the capsule by lowering the crane hook (hence, lifting bar) about 2 ft. The lifting bar is removed from the immediate area and disengaged from the overhead crane. The capsule is supported at the in-core end by the guide strips (lying on the bottom of HT-1), and at the out-of-core end by the capsule dolly. The ropes are used to pull the capsule the remaining 7 ft into HT-1. The adapter sleeve flange clamp is tightened down and the assembly is ready for purging and hydrostatic testing.

The coolant line is connected to the sample holder, the electrical and gas lines having been previously connected, and the sample holder is then lowered into the quadrant. A long-handled hook and a rope are used to insert the sample holder into the capsule. The capsule (to sample holder) flange clamp is tightened and this assembly is ready for purging and subsequent tests as described in Section 6.3.2.

6.3.2 <u>Operational and Hydrostatic Pre-Run Tests</u>

The following tests will be conducted before each experimental run. These tests should not be confused with the one set of initial pre-operational tests to be conducted after equipment installation.

Two tests will be conducted as found necessary. These are an instrument calibration test and a capsule water relief valve setting test. The other operational and hydrostatic tests will be run at times indicated below.

The system instrument calibrations would involve, for example, such instruments as the two flow transmitters (FX-1, FX-2) and the pressure transmitter (PX-1), as well as associated electrical tests. The capsule water relief valve (PC-V5) setting may require occasional checking. A manually operated hydro pump and associated pressure gage will be used.

The HT-1 hydro-test will be conducted after the capsule has been inserted into HT-1, to prove the integrity of the flanged joints between HT-1 and the adapter sleeve, and particularly between the sleeve and the capsule. The Quadrant A deionized water header, will be used to provide the hydraulic pressure. The interior of the capsule, the sample holder, and all piping and flexible hose between the capsule inlet and outlet isolation valves will not be subject to the hydraulic pressure.

After the HT-1 hydrotest, a pre-insertion operational test of the sample and actuating gas system will be run. The sample holder with all electrical and gas lines attached will be placed on the floor at the 0'0" elevation, a final out-of-pile test made to examine the ability to actuate the transducer sample and receive a satisfactory output signal.

Upon completion of the sample operational test, the sample holder is inserted into the capsule as indicated in Section 6.3.1, and the capsule hydro-test is then performed. This test is the final leak test before reactor power operation. The purpose of the test is to demonstrate the integrity of the various flanged joints, and in particular, the capsule back plate joint and the sample holder - flexible hose joint. After the capsule hydro-test, the experiment pre-start test is run. This is the last opportunity to determine proper transducer actuation and response for that set of transducers. The results of this test will be the standard against which radiation-induced malfunction or failure is measured. After this test is run, the transducers are irradiated, and only hot cell examinations can be made.

6.4 OPERATION

After the final pre-run tests are completed, a reactor startup will be initiated. During the approach to criticality and full power, the loop control panel will be monitored continuously, as well as the read-out equipment connected to the experiment. Loop data will be recorded at every new power level until full power is reached, and at full power, once every hour. Any abnormalities should be noted and the proper corrective action taken. The test specifications will outline the proper data-taking method for the experiment from before criticality until after shutdown. If an experiment requires a gas actuation system, the test specification will specify the pressures. The gas system accumulator is pre-charged and then released into the sample gas actuating system through SA-V1 until the desired pressure or pressures are reached. The gas pressure can be vented off through SA-V3.

A 63-05 operator's duties may consist of any or all of the following operations during a power run. He will record and check all loop and experimental data as indicated in the procedures, as well as perform general equipment maintenance.

6.5 POST-IRRADIATION HANDLING

The primary handling operation after the completion of the experimental run involves disconnecting the sample holder, transporting it, underwater, to the PBR hot cells for sample fixture testing, disassembly and ultimate disposal. In special cases it may be desirable to transport an experiment to the hot cells by means of a lead cask and cart through the air lock door.

6.5.1 Quadrant Operations

After the sample holder and capsule interior have been purged and the capsule clamp loosened, a long-handled hook is attached to the sample holder back plate lifting eye. The sample holder is pulled out, using the hook tool and a rope, until the back plate is far out enough to permit attaching a second hook tool to one of the sample holder guide rings. The sample holder is then completely removed from the capsule and placed on the quadrant floor. The chain fall and polar crane are used to lift the sample holder up through the quadrant to permit subsequent disconnecting of the gas and coolant lines. The sample holder is then returned to the quadrant floor to await transport to the PBR Hot Cells.

After the primary coolant pumps are shut down, HT-1 is purged of primary coolant. The adapter sleeve flange clamp is loosened and the capsule pulled partly out of HT-1 using a rope. The lifting bar is brought up under the capsule with the slot in the outer arm engaging the capsule flange, and the rope is then used to withdraw the capsule out of HT-1 with the lifting bar supporting the weight. The capsule front end is raised and set down off the south side of HT-1; the front (in-core) end of the capsule rests on the capsule stand. A long-handled hook is used to place the adapter sleeve cap in place, after which the flange clamp is tightened and HT-1 is purged of quadrant water.

6.5.2 Sample Holder Transport to Hot Cells

A cable is attached to the lifting eye on the back plate. Floats are attached to the free end of the cable and the experiment electrical leads. The sample holder is placed in a horizontal position on the quadrant floor in front of the underwater door into Canal E. With the door open, the leads and cable are pulled down and through the door out into the canal using a hook tool from the canal side of the door. The floats will bring the cable and leads up to the surface of the water, where they are retrieved. With the cable and leads transferred, the sample holder is moved through the door (using the cable and hook tool), out into the canal and over to the underwater door leading into Canal F. The same procedure is followed here. At the door into Canal J, the PBR underwater cable arrangement is used to transfer the sample holder, cable, and electrical leads.

6.5.3 Hot Cell Area Operations

At the back of the hot cells, the sample holder is placed in the lifting bar which is attached to a remotely operated crane. The two remotely operated cranes are used to transport the sample holder in the lifting bar from the canal floor to the lift tray on the Cell No. 1 door. The door is then remotely closed, carrying the lifting bar and sample holder into the hot cell with it. The in-cell General Mills manipulator and the two sets of master slave manipulators are used to move the sample holder and attached leads onto the cell working surface and into position for subsequent sample fixture disassembly, testing, and subsequent disposal.

7.0 CALCULATIONS

7.1 HEAT TRANSFER CALCULATIONS

7.1.1 Normal Cooling Water Exit Temperature

Summary

The data for gamma heating utilized are shown in Figure 7.1. Experimental values* of heat generation rate at 60 Mw reactor power were increased 20 per cent and used for these calculations. A value of 8 watts/g at a point 4 inches from the HT-1 centerline toward the core and 1.24 watts/g at a point 4 inches from the HT-1 centerline away from the core was used.* The average value of the gamma heat generation is therefore 4.62 watts/g at the HT-1 centerline, at a point on the HT-1 centerline nearest the core. The heat generation rate on the HT-1 centerline is described by the following linear equation.

$$\gamma_x = \gamma_c - \frac{x}{5.64}$$

where γ_x = Gamma heat generation rate x inches from core centerline on the HT-1 centerline
= watts/g

γ_c = Average gamma heat generation rate on HT-1 centerline at a point nearest the core
= 4.62 watts/g*

x = Distance on the HT-1 centerline from the horizontal core centerline

The peak value of 8 watts/g used above is 20 per cent greater than the peak experimental value for voided HT-1. Therefore, the 8 watts/g value is conservative. The heat loads transferred to the cooling water are given in Table 7.1 The normal exit cooling water temperature, assuming an inlet temperature of 135°F, 75 gpm flow, and the heat loads given in Table 7.1, was 153.6°F.

*Reference 7.1

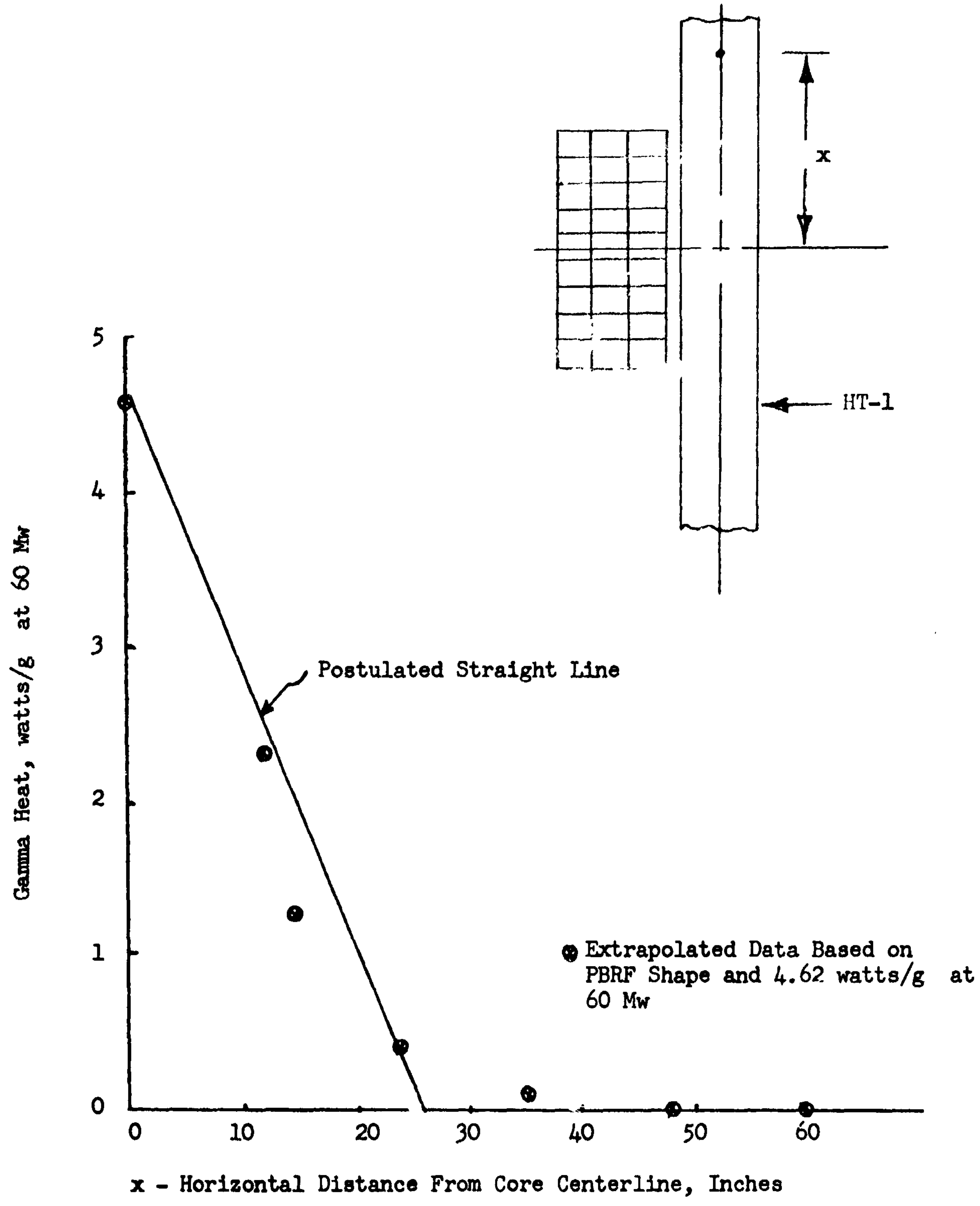


Figure 7.1 - Extrapolated Gamma Heating Distribution from Core Centerline

TABLE 7.1

Total Heat Load Transferred to Loop Cooling Water

Source of Heat			Heat Load (BTU/hr)
HT-1 Tube (Assuming an Even Split in Heat Transferred Between Inside and Outside)	Q_1*	=	136,000
Sample Holder	Q_2	=	9,240
Sample (Assuming 9 lb)	Q_3	=	60,800
Pressure Tube	Q_4	=	111,500
Heat Generated in Water	Q_5	=	377,900
	Q Total		695,400

*The values for Q_1 through Q_5 are further described in the following parts of this section.

7.1.1.1 Heat Transferred from HT-1 Tube

$$Q_1 = \frac{\pi/4\ (D_o^2 - D_i^2)\ L\rho\gamma_x\ (3.412)\ (454)}{2}$$

where: D_o = Tube outside diameter

= 10 inch

D_i = Tube inside diameter

= 9 inch

L = Tube length

= 52 inch

ρ = Aluminum tube density

= 0.098 lb/in^3

$^*\gamma_x$ = Average heat generation rate 13 inch from core centerline = L/4

= 2.31 watts/g

3.412 = Conversion factor - BTU/hr-watt

454 = Conversion factor - grams/lb

2 = Assume 1/2 of the heat transferred to loop cooling water

$$Q_1 = \frac{\pi/4\ (10^2-9^2)\ 52 \times 0.098 \times 2.31 \times 3.412 \times 454}{2}$$

= 136,000 BTU/hr

*See Section 7.1.1.

7.1.1.2 Heat Transferred from Sample Holder

$$Q_2 = \frac{L \times W \times \gamma_x \times 3.412 \times 454}{12}$$

where: L = Unitrace length

= 22 inch

W = Unitrace pipe weight

= 1.66 lb/ft

x = Average heat generation rate 15 inch from core centerline = L/2 + 4.0 in.

= 1.96 watts/g

3.412 = Conversion factor - BTU/hr-watt

454 = Conversion factor - grams/lb

12 = Conversion factor - in/ft

$$Q_2 = \frac{22 \times 1.66 \times 1.96 \times 3.412 \times 454}{12}$$

$$= 9{,}240 \text{ BTU/hr}$$

*See Section 7.1.1.

7.1.1.3 <u>Heat Transferred from Sample</u>

$$Q_3 = W \times \gamma_x \times 454 \times 3.412$$

where: W = Sample weight

= 9.0 lb

γ_x = Average heat generation rate of mass 1.5 inch from centerline of core.

= 4.359 watts/g

$$Q_3 = 9.0 \times 4.359 \times 454 \times 3.412$$

$$= 60{,}800 \text{ BTU/hr}$$

7.1.1.4 <u>Heat Transferred from Capsule Tube</u>

<u>Hemispherical Head</u>

$$Q_{4.1} = \frac{\pi D^2}{2} \left[\rho \gamma_x \, t \, (3.412)\,(454) \right]$$

where: D = Head diameter

= 8.5 inches

ρ = Aluminum density

= 0.098 lb/in^3

γ_x = Heat generation rate for mass centered 6.0 inch from core centerline

= 3.55 watts/g

t = Head thickness

= 0.1875 inch

$$Q_{4.1} = \frac{\pi(8.5)^2}{2}\left[0.098 \times 3.55 \times 0.1875 \times 3.412 \times 454\right]$$

= 11,500 BTU/hr

Cylindrical Section to Core Centerline

$$Q_{4.2} = \pi D t L \gamma_x \rho (3.412)(454)$$

where: D = Cylinder diameter

= 8.5 inch

t = Cylinder thickness

= 0.3125 inch

L = Cylinder length

= 4.5 inch

γ_x = Heat generation rate for the mass centered at L/2 (2.25 inch) from the core centerline

= 4.22 watts/g

ρ = Section density

= .098 lb/in^3

$$Q_{4.2} = \pi \times 8.5 \times 0.3125 \times 4.5 \times 4.22 \times .098 \times 3.412 \times 454$$

= 24,000 BTU/hr

Cylindrical Section from Core Centerline to Point of Zero Heat

$$Q_{4.3} = \pi D t L \gamma_x \rho (3.412)(454)$$

where: D = Section diameter

= 8.5 inch

t = Section thickness

= 0.3125

L = Section length

= 26.0 inch

γ_x = Heat generation rate for the mass centered at L/2 (13.0 inch) from the core centerline

= 2.31 watts/g

ρ = Section density

= 0.098 lb/in^3

$$Q_{4.3} = \pi \times 8.5 \times 0.3125 \times 26.0 \times 2.31 \times .098 \times 3.412 \times 454$$

$$= 76{,}000 \text{ BTU/hr}$$

Total Heat Transferred from Capsule Tube

$$Q_4 = Q_{4.1} + Q_{4.2} + Q_{4.3}$$

$$= 11{,}500 + 24{,}000 + 76{,}000$$

$$= 111{,}500 \text{ BTU/hr}$$

7.1.1.5 Total Heat Transferred to Cooling Water from Components

$$Q_{Total} = 111{,}500 + 60{,}800 + 9{,}240 + 136{,}000$$

$$= 317{,}500 \text{ BTU/hr}$$

7.1.1.6 Heat Generated by γ Heating in Cooling Water

Volume inside HT-1 γ heating zone $= \pi/4 \times 9^2 \times 52$ inch

$= 3310 \text{ in}^3$

Volume of capsule in γ heating zone

$$\text{Sample} = \frac{6 \text{ lb}}{.098} + \frac{3 \text{ lb}}{.29} = 61.3 + 10.3 = 71.6 \text{ in}^3$$

$$\text{Hemispherical head} = \frac{\pi D^2 t}{2} = \frac{\pi \times 8.5^2 \times 0.1875}{2}$$

$$= 21.2 \text{ in}^3$$

Cylindrical section to core centerline $= \pi DtL = \pi \times 8.5 \times .3125 \times 4.5$

$= 37.5 \text{ in}^3$

Cylindrical section from core centerline to zero γ heating

$$= \pi DtL = \pi 8.5 \times .3125 \times 26 = 216 \text{ in}^3$$

Sample holder

$$= \frac{1.66 \text{ lb}}{.098} \times 22 \text{ ft} = 37.2 \text{ in}^3$$

Total volume of capsule in γ heating zone $= 383.5 \text{ in}^3$

Volume of water in γ heating zone $= 3310 - 383.5$

$= 2926.5 \text{ in}^3$

Weight of water in heating zone $= \frac{2926.5}{1728} \times \rho = 105.6$ lb
(where ρ(water) $= 62 \text{ lb/ft}^3$)

Heat generation rate at L/2 (13 in) from core centerline

$$= 2.31 \frac{\text{watts}}{\text{gram}}$$

$$\text{Heat input per hr} = 105.6 \times 2.31 \times 454 \times 3.412$$

$$Q_5 = 377{,}900 \text{ BTU/hr}$$

7.1.1.7 Total Heat Load Transferred to Cooling Water

$$Q_{Total} = 377{,}900 + 317{,}500 = 695{,}400 \text{ BTU/hr}$$

7.1.1.8 Normal Cooling Water Exit Temperature

$$T_{exit} = 135 + \frac{Q_{Total}}{M\ Cp}$$

where: Q_{Total} = heat input = $695{,}400 \frac{BTU}{hr}$

M = flow rate lb/hr

$$= 75 \frac{gal}{min} \times .1337 \frac{ft^3}{gal} \times 62.4 \frac{lb}{ft^3} \times 60 \frac{min}{hr}$$

$$= 37600 \text{ lb/hr}$$

C_p = specific heat of water $1.0 \frac{BTU}{lb\text{-}°F}$

$$T_{exit} = 135 + \frac{695{,}400}{37600 \times 1.0}$$

$$= 135 + 18.6 = 153.6°F$$

The cooling water exit temperature under normal operating conditions of 75 gpm flow rate and 135°F inlet temperature, as shown above, is 153.6°F. Therefore, this temperature is well below the design temperature (300°F) of the system.

7.1.2 Maximum Capsule Temperature During Normal Operation

The maximum operating temperature was determined using the following assumptions:

Average heating rate at centerline of core and HT-1	$\cong$4.62 w/gm at 60 Mw
Water flow rate	75 gal/min
Pressure	145 psig (160 psia)
Capsule OD	8.5 inch
Capsule thickness	5/16 inch
HT-1 ID	9.0 inch
All heat transfer is to the outside	

The temperature of the tube wall was found to be 187.6°F which is well below the design temperature of 300°F. The calculations are shown below:

7.1.2.1 Water Temperature at Core Centerline

Water inlet temperature to HT-1 = 135°F

Heat transferred from HT-1 tube $= \frac{136,000}{2} =$ 68,000 BTU/hr

1/2 total heat generation in coolant $= \frac{377,900}{2} =$ 188,950

Use 188,900

Heat transferred from hemispherical head = 11,500

Heat transferred from cylindrical tube to core centerline = 24,000

Total 292,400 BTU/hr

Water temperature

$$= 135 + \left(\frac{292,400}{75 \times .1337 \rho\ 60 \times 1.0} \right) = 142.9°F \text{(See Section 7.1.1.8)}$$

7.1.2.2 Maximum Hot Spot Temperature of Capsule During Normal Operation

Equivalent diameter

$$D_e = D_1 - D_2 = 9.0 - 8.5 = 0.5 \text{ inch} = 0.0416 \text{ ft}$$

Area of annulus

$$= \frac{\pi}{4} (D_1^2 - D_2^2)$$

$$= 0.785 \left[\left(\frac{9.0}{12} \right)^2 - \left(\frac{8.5}{12} \right)^2 \right]$$

$$= 0.047 \text{ ft}^2$$

Heat generated in capsule wall

$$V = \text{Volume of tube per ft} = \frac{\pi}{4} \left[D_o^2 - D_i^2 \right] \times 12.0$$

$$= \frac{\pi}{4} \left[(8.5)^2 - (7.876)^2 \right] \times 12$$

$$= 96 \text{ in}^3$$

$$A = \text{Surface area per ft} = \frac{\pi(8.0) \times 12.0}{144}$$

$$= 2.09 \text{ ft}^2/\text{ft}$$

Assume heat generation rate $\gamma = 8.0$ watts/g

$$Q = \gamma \times V \times \rho \times 3.412 \times 454$$

$$Q = 8.0 \times 96.0 \times .098 \times 3.412 \times 454$$

$Q = 116{,}000$ BTU/hr

$$\frac{Q}{A} = \frac{116{,}000}{2.09} = 55{,}500 \text{ BTU/hr-ft}^2$$

Assume film temperature = 160°F

Then: $G = \frac{\text{Flow}}{\text{Unit Area}} = 7.82 \times 10^5 \frac{\text{lb}}{\text{hr-ft}^2}$

K = thermal conductivity of fluid = $0.385 \frac{\text{BTU}}{\text{hr-ft °F}}$

μ_b = viscosity of fluid = $0.970 \frac{\text{lb}}{\text{hr-ft}}$

C_p = specific heat of fluid = $1.0 \frac{\text{BTU}}{\text{lb-°F}}$

The film coefficient is calculated as follows:*

$$h_f = \frac{0.023\, C_p G}{\left(\frac{C_p \mu}{k}\right)^{2/3} \left(\frac{\mu_w}{\mu_b}\right)^{0.14} \left(\frac{D_e G}{\mu_b}\right)^{0.2}}$$

Let $\left(\frac{\mu_w}{\mu_b}\right) = 1.0$ (conservative)

$$h_f = 1222 \frac{\text{BTU}}{\text{hr-ft}^2\text{-°F}}$$

$$\Delta t = \frac{Q}{A} \times \frac{1}{h_f} = \frac{55{,}500}{1222}$$

$$= 45.3^\circ\text{F}$$

Therefore the maximum capsule wall temperature is:

$T_{max} = 142.9 + 45.3 = 188.2^\circ$F (at outside surface)

*See Reference 7.2, page 219.

7.1.3 Maximum Capsule Temperature (at Reactor Power Cut-Back)

The same assumptions are made for the following calculations as for those in Section 7.1.2, but using a coolant water flow of 50 gpm.

Therefore, assuming a coolant water flow of 50 gpm, the water temperature at the core centerline:

$$T = 135° + \frac{292,400}{50 \times .1337 \times \rho \times 60 \times 1.0}$$

$$= 146.8°F$$

then,

$$\Delta T = \frac{Q/A}{h_f}$$

where:

$$*h_f = \frac{0.023 C_p G}{\left(\frac{C_p \mu}{k}\right)^{2/3} \left(\frac{\mu_w}{\mu_b}\right)^{0.14} \left(\frac{DeG}{\mu}\right)^{0.2}}$$

and $\frac{Q}{A} = 65,000$ BTU/hr-ft^2

$G = 5.21 \times 10^5$ lb/hr-ft^2

$k = 0.385$ BTU/hr-ft°F

$\mu = 0.97$ lb/hr-ft

$C_p = 1.0$ BTU/l/°F

assume $\left(\frac{\mu_w}{\mu_b}\right)^{.14} = 1$

*See Reference 7.2, page 219.

then $h_f = 728$

$$T = \frac{65,000}{728} = 89°F$$

$$T_W = 146.8° + 89° = 235.8°F$$

7.1.4 Maximum Capsule Temperature During a Reactor Excursion

Assume reactor goes to 150% power. Flow remains at 75 gpm, and the inlet water temperature to HT-1 is 135°F. The heat loads to the coolant water are:

Heat generation in coolant	= 283,400 BTU/hr
Heat transferred from HT-1 tube	= 102,000
Heat transferred from hemispherical head	= 17,200
Heat transferred from cylindrical tube to core centerline	= 36,000
Total	438,600 BTU/hr

Water temperature at core centerline:

$$= 135° + \frac{438,600}{75 \times 0.1337 \times \rho \times 60 \times 1.0}$$

$$= 146.8°F$$

Maximum hot spot temperature of capsule: Using the procedure similar to that in 7.1.3,

$$\frac{Q}{A} = 97,500 \text{ BTU/hr-ft}^2$$

Assuming 160°F film temperature,

$$^*h_f = 1222 \text{ BTU/hr-ft}^2{}^\circ\text{F}$$

$$\Delta T = \frac{Q}{A} \left(\frac{1}{h_f}\right) = \frac{97,500}{1222} = 79.8^\circ\text{F}$$

then

$$T_{wall,\ maximum} = 146.8^\circ + 79.8^\circ$$

$$= 226.6^\circ\text{F}$$

Therefore, the maximum capsule temperature during a reactor excursion will be less than the design temperature (300°F).

*Refer to Section 7.1.2.2.

7.1.5 Exit Coolant Temperature During Reactor Excursion

Assume a reactor excursion to 150% power; flow, 75 gpm; and inlet water temperature, 135°F; then:

$$\text{Heat Load} = 695{,}400 \times 1.5 = 1{,}043{,}000 \text{ BTU/hr}$$

$$^{*}\text{Exit Temperature} = 135 + \frac{1{,}043{,}000}{75 \times 0.1337 \times \rho \times 60 \times 1.0}$$

$$= 135° + 27.8°$$

$$= 162.8°F$$

7.1.6 Maximum Capsule Temperature at Scram Flow

Loss of coolant flow below 50 gpm will initiate a reactor scram. If however, the flow drops to just above 50 gpm, no scram will occur. To determine if a flow reduction to 50 gpm is hazardous, an analysis shows that at full reactor power and a drop in coolant flow to 50 gpm, the pressure tube wall temperature rises to 235.8°F maximum, which is below the design temperature of 300°F.

In view of this, a set point of 50 gpm is considered safe for reactor scram, since no rupture of the inner tube is expected. The calculations are presented in Section 7.1.3.

*See Section 7.1.1.8 for units.

7.2 FLUID FLOW CALCULATIONS

The following pressure drop calculations describe the HT-1 system with the WANL water-cooled experiment inserted. These calculations provide a conservative estimate of the effect of the 3-inch diameter coolant piping installed at PBRF, and indicate that flows in excess of the 75 gpm (used as a nominal flow in other calculations) will exist in the experiment.

7.2.1 Calculation Method

Data from PBRF* indicates that the 1-1/2 inch interconnecting piping, less piping for the WANL water-cooled experiment, gave 75-78 gpm and a Δp of 53 psi. Calculations are based on 75 gpm flow and 53 psi pressure drop from the PBRF measurement.

PBRF has increased the pipe size to 3-inch which produces approximately 130 gpm at 53 psi.

$$\Delta p \ \mathrm{lb/in^2} = \frac{f\ W_1^2\ V_m L}{2\ g_c\ r_h \times 144 \times A^2}$$ (Using modified Darcy's formula)

Where W_1 = lb/sec

$V_m = \mathrm{ft^3/lb}$

$g_c = 32.2\ \mathrm{ft/sec^2}$

$r_h = De/4 = \mathrm{ft}$

$L = \mathrm{ft}$

$A = \mathrm{ft^2}$

$$5000 < Re < 200{,}000 \quad f_m = \frac{0.046}{Re^{0.2}}$$

$$Re = \frac{De\ W/A}{\mu_m}$$

*See Section 7.1.

Where De = ft

W = lb/hr

μ_m = lb/ft-hr

$W_1 = \frac{W}{3600}$

Therefore the above formula can be rearranged as follows:

$$\Delta p \text{ psi} = \frac{0.046\,\mu^{0.2}}{De^{0.2}\ W^{0.2}} \times \frac{W^2}{(3600)^2} \times \frac{v_m}{2(32.2)144} \times \frac{4\ L \times A^{0.2}}{D_e\ A^2}$$

$$= \frac{(0.046)4}{(3.6 \times 10^3)^2\ (2)\ (32.2)\ (144)} \times \left(\frac{L}{A^{1.8}\ De^{1.2}}\right)\left(V_m^{0.2}\right)\left(W^{1.8}\right)$$

$$\Delta p \text{ psi} = 1.53 \times 10^{-12} \left(\frac{L}{A^{1.8}\ De^{1.2}}\right)\left(V_m\ ^{0.2}\right)\left(W^{1.8}\right) = \text{New Basic Formula}$$

7.2.2 PBRF Piping Pressure Drop

Rearranging the formula, assuming 125°F temperature, 130 gpm, and 53 psi drop:

$$\left(\frac{L}{A^{1.8}\ De^{1.2}}\right) = \frac{53}{1.53 \times 10^{-12} \times 1.71 \times 10^{-2} \times 5.25 \times 10^{8}}$$

This function,

$$\left(\frac{L}{A^{1.8}\ De^{1.2}}\right) = 3.85 \times 10^{6}$$

is now used as a non-temperature dependent constant.

Using the above determined functions in the new basic formula and assuming an average fluid temperature of 145°F, and 75 gpm flow,

if

$$V_{145} = 0.0163$$

$$\mu_{145} = 1.095$$

$$\mu^{0.2} = 1.0183$$

$$V \mu^{0.2} = 1.66 \times 10^{-2}$$

$$W^{1.8} = 1.69 \times 10^{8}$$

then Δp is as follows:

$$\Delta p = 1.53 \times 10^{-12}\ (3.85 \times 10^{6})\ (1.66 \times 10^{-2})\ (1.69 \times 10^{8})$$

$$\Delta p = 16.5 \text{ psi}$$

7.2.3 WANL Experiment Pressure Drop Estimate

Solid Pipe - All pipe and fittings taken as 2 inch Schedule 40 (conservative).

$L \cong$	50 ft

Flexible Pipe - Assume equivalent to 3 times its length of 2 inch Schedule 40 pipe and 10 bends at 4 equivalent ft each.

(37 ft flexible pipe x 3) + 40 =	155 ft

Pipe Fittings - All taken as 2.0 inch ID

Four 90° long radium elbows = 6.6 ft
Two 2 inch x 2 inch x 2 inch T's = 3.3 ft
Three 45° elbows = 4 ft

TOTAL = 13.9 ft, use	14 ft

Valves - All taken as 2 inch

Two globe valves (open) = 114 ft
One lift check = 57 ft

TOTAL =	171 ft
Therefore, total length of 2 inch equivalent pipe =	390 ft

Utilizing dimensions for 2 inch pipe noted above

and

$$\Delta p = 1.53 \times 10^{12} \left(\frac{L}{A^{1.8}\ De^{1.2}}\right)\left(V_m \mu^{0.2}\right)\left(W^{1.8}\right)$$

At 75 gpm,

$$\text{Total}\ \Delta p = 14.3 \text{ psi}$$

HT-1 Area Around Capsule (75 gpm @ 145°F)

Entrance into annular space from HT-1:

$$*\Delta p = \frac{(v_1^2 - v_2^2) + K_c\, v_1^2}{144 \times 2 \times gc}$$

where:

$v_1 = 3.44$ ft/sec

$v2 = 0.374$ ft/sec

$K_c = 0.05$ - Entrance coefficient

$\rho = \frac{1}{0.0163} = 61.3$ lb/ft^3

$\Delta p = 0.082$ psi @ 75 gpm

Annular Space Pressure Drop

$$\Delta p = \frac{\rho f^L\, v^2}{144 D 2g}$$

$v = 3.44$ ft/sec

$f = 0.026$

$\Delta p = 0.404$ psi

*Reference 7.2

Therefore, total Δp of HT-1 + Annular Space = 0.082 + 0.404 = 0.486 psi

Water Entering Adapter Sleeve

$$\text{Max loss } \Delta p \text{ psi} = \frac{v^2 \rho}{2 \times g \times 144}$$

$$\Delta p = \qquad 0.141 \text{ psi}$$

"Unitrace" Losses - Estimated as 12 ft of 2 inch Schedule 40 pipe

$$^{*}\Delta p = 1.53 \times 10^{-12} \left(\frac{1.2 \times 10^{1}}{1 \times 10^{-3} \times 1.17 \times 10^{-1}} \right) \times \left(1.66 \times 10^{-2}\right) \left(1.69 \times 10^{8}\right)$$

$$\Delta p \text{ psi} = \qquad 0.44 \text{ psi}$$

Sample Fixtures

Sample fixtures will vary and be quite intricate. Pressure drops estimated for this calculation,

@ 75 gpm = 3.0 psi

180° Turn

180° turn is $\cong$ to 13 ft of 2 inch pipe

or

$$\Delta p \text{ psi} = \qquad 0.48 \text{ psi}$$

*Reference Equation Section 7.2.3

Return Internal to Capsule, External to "Unitrace"

if:

$A = 0.307 \text{ ft}^2$ - flow area

$A^{1.8} = 0.12$

$D_e = 0.46$ ft - equivalent diameter

$D_e^{1.2} = 0.394$

$$*\Delta p = 1.53 \times 10^{-12}\left(\frac{1.2 \times 10^2}{0.12 \times .394}\right)\left(1.66 \times 10^{-2}\right)\left(1.69 \times 10^8\right)$$

Δp psi $= 1.01 \times 10^{-3}$ psi

or Δp considered as = 0 psi

Orifice Plate Pressure Drops

The orifice plates (2 each) are designed for 50 inch of water drop/100 gpm. At 75 gpm each orifice plate will have 1 psi drop. Therefore, 2 will have a drop equal to 2.0 psi.

To Summarize,

the total Δp at 75 gpm is as follows:

PBRF Piping	16.5 psi
WANL Piping	14.3 psi
HT-1 and Capsule Annulus	0.486 psi
Entering Adapter Sleeve	0.141 psi
Test Fixture	3.000 psi
Unitrace Pipe	0.44 psi
180° Turn	0.48 psi
Return in Capsule	0
Orifice Plates (2)	2.000 psi
Required available pressure drop @ 75gpm =	37.347 psi
Available Δ p =	53 psi

Therefore, 75 gpm will be exceeded by the system with all valves open.

*Reference Equation Section 7.2.3.

7.3 NUCLEAR CALCULATIONS

7.3.1 Activation Calculations

Materials

The strain gage fixture is composed of aluminum and 304L stainless steel. Trace quantities of other materials will be present, that is, the strain gage materials and instrument leads; however, the mass involved is so small compared to the mass of the fixture that these materials will be neglected in the activation calculation.

That part of the sample holder which resides in a high flux region (11.25 inch) will be included in the activation analyses. The sample holder is fabricated from 6061 aluminum.

Primary Activation Products

The primary activation products, parent isotopes, element and isotope fractions and decay information are presented in Table 7.2. The decay schemes are shown in Table 7.3.

Irradiation Parameters

Irradiation time = 10 days = 8.64×10^5 sec
Decay time in quadrant before disconnecting experiment = 1 day = 8.64×10^4 sec
Mass of stainless steel irradiated = 2.05 lb
Mass of aluminum irradiated = 6.74 lb
Thermal neutron flux = 4×10^{14} n/cm^{2}sec
Fast neutron flux (for Al^{27} (n,α) Na^{24} reaction, threshold energy for neutrons is 8 Mev)

$$\phi_f \simeq 4 \times 10^{12} \text{ n/cm}^2\text{sec}$$

Decay time before experiment is removed from quadrant = 10 days = 8.64×10^5 sec.

Table 7.2

Primary Activation Products*

Activation Product	Half-Life	λ Sec^{-1}	Energy and Yields, Mev, Percent	Parent Isotope and Reaction	Percent Element in Al**	Percent Element in SS	Isotopic Percent	Grams of Parent Isotope	σ Act, Barns
Na^{24}	15.0h	1.28×10^{-5}	2.75^{100}, 1.37^{100}	$Al^{27}(n,\alpha)$	100	0	100	3060	0.05
Cr^{51}	27.8d	2.88×10^{-7}	0.32^{10}	$Cr^{50}(n,\gamma)$	0	20.0	4.31	8.0	11
Fe^{55}	2.6y	8.45×10^{-9}	No γ	$Fe^{54}(n,-)$	0.7	64.6	5.84	35.8	2.2
Mn^{56}	2.58h	7.47×10^{-5}	0.84^{99}, 1.81^{23}, 2.11^{14}	$Mn^{55}(n,\gamma)$	0.15	2.0	100	23.2	13.4
Co^{60m}	10.5m	1.10×10^{-3}	$0.059^{99.7}$, $1.33^{0.3}$	$Co^{59}(n,\gamma)$	0.40	0.25	100	12.5	16.0
Co^{60}	5.27y	4.17×10^{-9}	1.33^{100}, 1.17^{100}	$Co^{59}(n,\gamma)$	0.40	0.25	100	12.5	20.0
Cu^{64}	12.9h	1.49×10^{-5}	1.34^{1}, 0.51^{38} (from β^{+} annihilation)	$Cu^{63}(n,\gamma)$	0	0.50	69.1	3.21	3.9
Ni^{65}	2.56h	7.51×10^{-5}	1.49^{20}, 1.11^{10}, 0.37^{3}	$Ni^{64}(n,\gamma)$	0.25	11.0	1.16	1.27	2.6
Zn[illegible]m	13.9h	1.39×10^{-5}	0.44^{100}	$Zn^{68}(n,\gamma)$	0.25	0	18.56	1.34	0.10
Zn[illegible]	57m	2.03×10^{-4}	No γ	$Zn^{68}(n,-)$	0.25	0	18.56	1.34	1.0

*References 7.3 and 7.4

** The [illegible]mum content of each element has been chosen to maximize activation.

Table 7.3

Decay Schemes

$${}_{11}Na^{24} \xrightarrow{\beta^-} {}_{12}Mg^{24} \text{ (Stable)}$$

$${}_{24}Cr^{51} \xrightarrow{\text{E.C.}} {}_{23}V^{51} \text{ (Stable)}$$

$${}_{26}Fe^{55} \xrightarrow{\text{E.C.}} {}_{25}Mn^{55} \text{ (Stable)}$$

$${}_{27}Co^{60m} \xrightarrow{\text{I.T.}(99\%)} {}_{27}Co^{60} \xrightarrow{\beta^-} {}_{28}Ni^{60} \text{ (Stable)}$$

$${}_{27}Co^{60m} \xrightarrow{\beta^-\ (0.3\%)} {}_{28}Ni^{60} \text{ (Stable)}$$

$${}_{27}Co^{60} \xrightarrow{\beta^-} {}_{28}Ni^{60} \text{ (Stable)}$$

$${}_{29}Cu^{64} \xrightarrow{\text{E.C.}(43\%) \text{ or } \beta^+(19\%)} {}_{28}Ni^{64} \text{ (Stable)}$$

$${}_{29}Cu^{64} \xrightarrow{\beta^-(38\%)} {}_{30}Zn^{64} \text{ (Stable)}$$

$${}_{28}Ni^{65} \xrightarrow{\beta^-} {}_{29}Cu^{65} \text{ (Stable)}$$

$${}_{30}Zn^{69m} \xrightarrow{\text{I.T.}(100\%)} {}_{30}Zn^{69} \xrightarrow{\beta^-} {}_{31}Ga^{69} \text{ (Stable)}$$

$${}_{30}Zn^{69} \xrightarrow{\beta^-} {}_{31}Ga^{69} \text{ (Stable)}$$

Sample Calculations

For all isotopes except Co^{60} and Zn^{69}, the buildup and decay equations normally used will be applicable, i.e.,

$$A(t,T) = \lambda N(t,T) = N_o \sigma_{act} \phi (1-e^{-\lambda t}) e^{-\lambda T}$$

A = activity of sample, dps
λ = decay constant for the radioisotope = 0.693/T 1/2, sec^{-1}
T 1/2 = half-life of radioisotope, sec
N(t,T) = number of atoms of radioisotope irradiated for t seconds and allowed to decay for T seconds
σ_{act} = activation cross section of parent isotope, cm^2 / atom
ϕ = neutron flux, n/cm^2sec
N_o = number of atoms of the parent isotope in sample before irradiation

Thus, as an example, for Al^{27} (n,α) Na^{24}

mass Al^{27} = 3060g

$$N_o = \frac{3060g}{27g/g\ mole} \times \frac{6.025 \times 10^{23}\ atoms}{g\ mole} = 6.81 \times 10^{25} \text{ atoms of } Al^{27}$$

$\sigma_{act} = 0.05 \times 10^{-24}\ cm^2/atom$

$\phi = 4 \times 10^{12}\ n/cm^2sec$

$\lambda = 1.28 \times 10^{-5}$ sec

$\lambda t = 1.28 \times 10^{-5} \times 8.64 \times 10^5 = 11.07$ (irradiation time)

$1-e^{-\lambda t} \cong 1.0$

$\lambda T_1 = 1.28 \times 10^{-5} \times 8.64 \times 10^4 = 1.107$ (decay time before disconnection)

$e^{-\lambda T_1} = 0.332$

$\lambda T_2 = 11.07$ (total decay time in quadrant)

$e^{-\lambda T_2} = 1.5 \times 10^{-5}$

At the end of the irradiation cycle, T = 0:

$$A(t,0) = 6.81 \times 10^{25} \times 0.05 \times 10^{-24} \times 4 \times 10^{12} \times 1.0 \times 1.0$$

$$= 1.36 \times 10^{13} \text{ dps}$$

$$= \frac{1.36 \times 10^{13}}{3.7 \times 10^{10}} = 368 \text{ curies}$$

where 3.7×10^{10} = dps/curie

At T_1 = 24 hr:

$$A(t,24 \text{ hr}) = A(t,0)\, e^{-\lambda T_1} = 368 \times 0.332$$

$$= 122 \text{ curies}$$

At T_2 = 10 days:

$$A(t,10 \text{ days}) = A(t,0)\, e^{-\lambda T_2} = 368 \times 1.5 \times 10^{-5}$$

$$= 5.52 \times 10^{-3} \text{ curies} = 5.52 \text{ mc}$$

For the cases of Co^{60} and Zn^{69}, two radioiscotopes are formed with the metastable isotopes decaying to the radioisotopes in question. Thus, the differential equation describing buildup and decay will be

$$dN_m/dt = N_o \sigma_m \phi - \lambda_m N_m \qquad \text{(Equation 1)}$$

$$dN/dt = N_o \sigma \phi + \lambda_m N_m - \lambda N \qquad \text{(Equation 2)}$$

where subscript m refers to Co^{60m} and Zn^{69m}, the metastable radioisotopes, and the non-subscripted symbols refer to Co^{60} and Zn^{69}.

The solution to Eq (1) has been given previously as

$$\lambda_m N_m = N_o \sigma_m \phi (1-e^{-\lambda_m t}) \text{ during irradiation.}$$

Thus, during irradiation

$$dN/dt = N_o \sigma \phi + N_o \sigma_m \phi - N_o \sigma_m \phi e^{-\lambda_m t} - \lambda N$$

The equation may be solved by the Laplace transformation, i.e.,

$$SN(S) = \frac{N_o (\sigma + \sigma_m)\phi}{S} - \frac{N_o \sigma_m \phi}{S+\lambda_m} - \lambda N(S)$$

$$N(S) = \frac{N_o (\sigma + \sigma_m)\phi}{S(S+\lambda)} - \frac{N_o \sigma_m \phi}{(S+\lambda)(S+\lambda_m)}$$

$$N(t) = \frac{N_o (\sigma + \sigma_m)\phi}{\lambda} (1-e^{-\lambda t}) - \frac{N_o \sigma_m \phi}{\lambda - \lambda_m} (e^{-\lambda t} - e^{-\lambda_m t})$$

$$\lambda N(t) = N_o (\sigma + \sigma_m) \phi (1-e^{-\lambda t}) - \frac{\lambda N_o \sigma_m \phi}{\lambda - \lambda_m} (e^{-\lambda t} - e^{-\lambda_m t})$$

Following irradiation, N(t,T) will contain a source term, S(T),

$$S\ (T) \cong N_m\ (t,0)\ (1-e^{-\lambda_m T})\ e^{-\lambda T}$$

i.e., the metastable isotopes are assumed to decay to Co^{60} and Zn^{69}. Also, N(t) decays after irradiation according to $e^{-\lambda T}$.

$$\text{Thus,}\quad N(t,T) = \frac{N_o\ (\delta + \delta_m)\ \phi}{}\ (1-e^{-\lambda t}) + \frac{N_o \delta_m \phi}{\lambda - \lambda_m}\ (e^{-\lambda t} - e^{-\lambda_m t})$$

$$+ N_m\ (t,0)\ (1-e^{-\lambda_m T})\qquad e^{-\lambda T}$$

$$A(t,T) = \lambda N(t,T) = \left[N_o\ (\delta + \delta_m)\ \phi\ (1-e^{-\lambda t}) + \frac{\lambda N_o \sigma_m \phi}{\lambda - \lambda_m}\ (e^{-\lambda t} - e^{-\lambda_m t}) \right.$$

$$\left. + \lambda N_m\ (t,0)\ (1-e^{-\lambda_m t}) \right]\ e^{-\lambda T} \qquad \text{(Equation 3)}$$

For Co^{60} and Co^{60m}

$$N_o = \frac{12.5 g}{59\ g/g\ mole}\ \times 6.025 \times 10^{23}\ \frac{atoms}{g\ mole} = 1.28 \times 10^{23}\ atoms$$

$$\delta_m = 16.0 \qquad\qquad \delta = 20.0$$

$$\phi = 4 \times 10^{14}$$

$$\lambda_m = 1.10 \times 10^{-3} \qquad\qquad \lambda = 4.17 \times 10^{-9}$$

$$\lambda_m t = 9.5 \times 10^{2}$$

$$1-e^{-\lambda_m t} \cong 1.0$$

$$\lambda_m T_1 = 95$$

$$1-e^{-\lambda_m T_1} = 1.0$$

$$\lambda_m T_2 = 9.5 \times 10^2$$

$$1-e^{-\lambda_m T_2} \cong 1.0$$

$$\lambda t = 3.60 \times 10^{-3}$$

$$1-e^{-\lambda t} = 3.62 \times 10^{-3}$$

$$\lambda T_1 = 3.60 \times 10^{-4}$$

$$e^{-\lambda T_1} \cong 1.0$$

$$\lambda T_2 = 3.60 \times 10^{-3}$$

$$e^{-\lambda T_2} = 0.9964$$

$$N_m (t,0) = \frac{1.28 \times 10^{23} \times 16.0 \times 10^{-24} \times 4 \times 10^{14} \times 1.0}{1.10 \times 10^{-3}}$$

$$= 7.45 \times 10^{17} \text{ atoms}$$

Using Eq (3)

$$A(t,0) = \left[1.28 \times 10^{23} (20 + 16) \times 10^{-24} \times 4 \times 10^{14} \times 3.62 \times 10^{-3} + \frac{4.17 \times 10^{-9} \times 1.28 \times 10^{23} \times 16 \times 10^{-24} \times 4 \times 10^{14}}{4.17 \times 10^{-9} - 1.10 \times 10^{-3}}\right]$$

$$= 6.66 \times 10^{12} - 3.10 \times 10^{9} = 6.66 \times 10^{12} \text{ dps}$$

$$= \frac{6.66 \times 10^{12}}{3.7 \times 10^{10}} = 180 \text{ curies}$$

At $T_1 = 24$ hr:

$$A(t,\ 24\text{ hr}) = \left[6.66 \times 10^{12} + 4.17 \times 10^{-9} \times 7.45 \times 10^{17} \times 1.0\right] 1.0$$

$$= 6.66 \times 10^{12} + 3.10 \times 10^{9} = 6.66 \times 10^{12}$$

$$= 180 \text{ curies}$$

At $T_2 = 10$ days:

$$A(t,\ 10\text{ days}) = 180 \times 0.9964 = 179.5 \text{ curies}$$

All other activation calculations are tabulated in Table 7.4, using the methods described above.

TABLE 7.4

Sample Activity

Activation Product	N_o	ϕ*	Activity at Decay Time T, Curies T=0	T=24 hr	T=10 days
Na^{24}	6.81×10^{25}	4×10^{12}	368	122	5.52×10^{-2}
Cr^{51}	9.44×10^{22}	4×10^{14}	2,460	2,400	1920
Fe^{55}	4.00×10^{23}	4×10^{14}	69.5	69.5	69.0
Mn^{56}	2.54×10^{23}	4×10^{14}	36,800	58.5	0
Co^{60m}	1.28×10^{23}	4×10^{14}	22,000	0	0
Co^{60}	1.28×10^{23}	4×10^{14}	180	180	179.5
Cu^{64}	3.07×10^{22}	4×10^{14}	1,300	360	0
Ni^{65}	1.20×10^{22}	4×10^{14}	336	5.35×10^{-2}	0
Zn^{69m}	1.19×10^{22}	4×10^{14}	12.8	3.86	0
Zn^{69}	1.19×10^{22}	4×10^{14}	141	8.25×10^{-6}	0
TOTAL			63,365	3,194	2,169

*e: No flux depression has been considered for the sample, thus making the calculated activities greater than that which will be obtained experimentally.

7.3.2 Assumptions for Shielding Calculations

During the two operations discussed below, the adequacy of the shielding is calculated, since these two operations are considered to present the greatest hazard to personnel from gamma radiation. First, shortly after irradiation, the capsule will be raised in the quadrant until the flange, located 12 ft from the nearest point on the sample fixture, can be manually disconnected. For purposes of calculation, the following assumptions will be made:

The sample fixture is a point source.
The capsule is filled with water.
The flange is 1 ft above the water when disconnected, giving a water shield thickness of 11 ft.
Disconnection is accomplished 24 hr after the irradiation period.

The second operation of interest is the removal of the sample fixture from the remainder of the capsule. This will be performed in a PBRF hot cell. It is assumed that this function is performed 24 hr after irradiation.

The dose rate obtained from a point source may be found from the formula:

$$\text{Dose rate} = \frac{S_0 B}{4\pi a^2 K} e^{-\mu t}$$

$$k = \frac{(\gamma(E)/cm^2 sec}{mr/hr} \qquad \text{(Reference 7.5)}$$

S_o = source strength, γ/sec

B = buildup factor

a = distance between source and dose point, cm

μ = attenuation coefficient of the shield for γ rays of energy E, cm^{-1}

Table 7.5 shows that at the time of capsule disconnection, taken to be 24 hr after shutdown, the dose rate at the surface of the water will be 0.18 mr/hr.

TABLE 7.5

Dose Rates During Flange Disconnection

E_γ	$\mu(H_2O)$, cm^{-1}	μ_t	B	e^{-ut}	$\frac{BS_o}{4\pi a^2}$*	ϕ $\gamma/cm^2 sec$	k	Dose Rate, mr/hr
2.75	0.041	13.74	11.9	1.04×10^{-6}	4.1×10^{7}	4.3×10^{1}	2.4×10^{2}	.18
1.33	0.060	20.1	52.7	1.7×10^{-9}	4.5×10^{8}	7.7×10^{-1}	4.1×10^{2}	1.8×10^{-3}
1.17	0.064	21.4	73.4	4.8×10^{-10}	4.6×10^{8}	2.2×10^{-1}	4.8×10^{2}	4.6×10^{-4}
0.51	0.096	32.2	1.8×10^{3}	9.7×10^{-15}	1.8×10^{10}	1.7×10^{-4}	9.5×10^{2}	1.8×10^{-7}
							TOTAL	.18 mr/hr

*a = [illegible]

To determine the adequacy of the hot cell shielding to protect operating personnel while working on the capsule, comparison with allowable activities will be made. The PBRF hot cell yields a dose rate of 2 mr/hr at the outer surface when the contained source is :

10^6 curies at 1 Mev

750 curies at 2.5 Mev

Since the capsule will be disconnected 24 hr after shutdown, hot cell work must post-date that time. Data from Table 7.6 indicates that, at 24 hr after shutdown, only 130 curies of gamma rays at 2.75 Mev and 688 curies gamma rays with energy greater than 1 Mev will occur. Thus, the hot cell is assumed adequate for all operations following disconnection of the capsule.

TABLE 7.6

Grouped Source Strength 24 Hr After Shutdown

Group $E\gamma$, Mev	Constituent Isotopes and γ Energy	Curies of Isotope	Source Strength of Group, dps
2.75	Na^{24}, 2.75	122	4.8×10^{12}
	Mn^{56}, 2.11	8	
1.33	Na^{24}, 1.37	122	
	Co^{60m}, 1.33	0	
	Co^{60}, 1.33	180	1.2×10^{13}
	Cu^{64}, 1.34	4	
	Ni^{65}, 1.49	0	
	Mn^{56}, 1.81	13	
1.17	Co^{60}, 1.17	180	
	Ni^{65}, 1.11	0	$.8 \times 10^{12}$
	Mn^{56}, 0.84	58.5	
0.51	Cr^{51}, 0.32	240	
	Cu^{64}, 0.51	137	1.4×10^{13}
	Ni^{65}, 0.37	0	
	Zn^{69m}, 0.44	4	
0.059	Co^{60m}, 0.059	0	0

7.3.3 Experiment Reactivity

The Plum Brook Reactor Facility staff has suggested an empirical method to determine order of magnitude reactivity effects for the RFI 63-05 experiment conducted in HT-1. This calculational method is proposed by the PBRF as a substitute manner of determining reactivity effects, rather than continually measuring this effect for each experiment.

Calculations have been made, following the suggested procedure, for a 9 lb experiment containing 7 lb of aluminum and 2 lb of stainless steel. According to the procedure, aluminum is to be treated as a void. The aluminum mass's worth is then determined by a ratio, considering that:

> HT-1 voided produces a negative reactivity of 60 cents. Masses far from core have little effect which leads to a significant volume of 9" diameter by 28" long.

The second part of the recipe is to take an average value of 1/3 cent/cm^2 for an absorber in the significant volume in HT-1. Determining $\Sigma_a V$ and multiplying by 1/3 cent/cm^2 gives the effect for the absorber. In calculating $\Sigma_a V$, the stainless steel was considered to be iron only.

For an assumed experiment mass and capsule, a reactivity effect of 16.76 cents is calculated. This result is considered to be grossly conservative. This position is substantiated by comparison of the experimental value with the calculated value using the suggested procedure. In this particular experiment, the calculated value was greater than the experiment value by a factor of 4.3.

7.3.3.1 Reactivity Change for W-2 Capsule

Capsule is 6061-T6 Aluminum, O.D.= 8.5", I.D.= 7.875"
L = 14 + 4.5

Metal Vol. back to 14" from core centerline:

$$V_{cyl} = (\pi/4)(D_2^2 - D_1^2)\,L = (\pi/4)(D_2 + D_1)(D_2 - D_1)\,L$$

$$= 0.785\ (8.5 + 7.875)(8.5 - 7.875)(18.5)$$

$$V_{cyl} = 148.4\ \text{in}^3$$

$$V_{head} = \frac{4/3\pi)(r_2^3 - r_1^3)}{2} = 2.093\ (4.25^3 - 3.94^3)$$

$$V_{head} = 33.0\ \text{in}^3$$

Metal Vol. = 148.4 + 33.0 = 181.4 in.^{3}; use 181 in.^{3}

The Reactivity Change is calculated assuming that the volume of metal in the capsule displaces an equal volume of water in the flooded HT-1.

$$\text{HT-1 vol.} = (\pi/4)\, D^2 L = 0.785(9^2)(28)$$

$$\text{HT-1 vol.} = 1781 \text{ in}^3$$

$$\frac{60}{1781} = \frac{X}{181}$$

$$X = 6.1 \text{ cents}$$

7.3.3.2 <u>Reactivity Change for Sample Fixture and Sampleholder</u>

Assume 7 lb Aluminum, 2 lb stainless steel in sample fixture and sample-holder.

Worth of Aluminum

$$\text{Vol. of Al} = (7 \text{ lb}) \left(\frac{1}{169} \text{ ft}^3/\text{lb}\right)(1728 \text{ in}^3/\text{ft}^3) = 72 \text{ in}^3$$

$$\frac{72}{1781}(60) = 2.42 \text{ cents}$$

Worth of stainless steel

$$\Sigma_a V = \rho \frac{N_o}{A} \sigma_a V = \frac{m N_o}{A} \sigma \qquad m = \rho V$$

$$m = (2 \text{ lb})(454 \text{ gm/lb})$$

$$= \frac{908\,(0.602)}{56}(2.53) \qquad m = 908 \text{ gm}$$

$$\Sigma_a V = 24.7 \text{ cm}^2 \qquad No = 0.602 \times 10^{+24}$$

$$A = 56$$

$$\frac{1}{3}\,\frac{\text{cent}}{\text{cm}^2}\; 24.7 \text{ cm}^2 = 8.24 \text{ cents} \qquad \sigma a = 2.53 \times 10^{-24} \text{cm}^2$$

Total worth of sample: 2.42¢ + [illegible]

7.3.3.3 Total Reactivity Change for Experiment

Capsule	6.1
Sample	10.66
	16.76

Total Worth = 16.76 cents

7.3.3.4 Comparison With Experimental Values

Strain Gage Experiment

Sample comprised 7 lb Aluminum + 2 lb stainless steel

Measured effect was 3.9 cents

Calculated effect: 16.76 cents

$$\frac{\text{calc}}{\text{exp}} = \frac{16.76}{3.9} = 4.3$$

7.4 STRESS CALCULATIONS

7.4.1 Stress Calculations of Capsule Assembly

The following design calculations were made to evaluate the structural integrity of the test capsule design. The calculations, which include determinations of pressure stresses, thermal stresses and beam deflection of the capsule, confirm the validity of the conservative design specifications.

The capsule shell was examined for ability to withstand collapsing pressures, according to ASME Code requirements. The minimum pressure difference which might collapse the tube is 260 psi with a safety factor of 4. The maximum pressure difference is 138 psi.

The maximum beam deflection is 0.001734 inch. Since the annulus is 0.25 inch the capsule bending is insignificant. The beam deflection will not cause permanent deformation of the capsule.

The internal pressure capability of the capsule system in the pool is significantly greater than the 160 psia maximum reactor pressure.

The maximum axial thermal stress is 740 psi. This stress would allow an infinite number of thermal cycles.

The capsule will easily withstand any foreseeable experimental mechanical and thermal stresses.

7.4.1.1 Outer Capsule Shell in Reactor (Aluminum)

The outer shell of the capsule is constructed of a 6061-T6 aluminum drawn tube with a hemispherical head welded to the inpile end position. The inpile aluminum tube is designed to resist an external pressure difference of 138 psi. This is the maximum pressure difference which can occur across the tube wall. It will occur if the hose carrying primary coolant into the capsule back section ruptures, dropping the pressure inside the capsule to that of the quadrant water at that level, which is 22 psia. Calculations for the minimum required thickness have been based on ASME Code design values and are as follows:

Design Parameters:

Outside diameter of tube	= 8.50 inch
Wall temperature	= 300°F
Material	= 6061-T6
External pressure difference	= 138 psi
Mod. elasticity	= 9.5×10^6

The ASME Code does not have curves for Al 6061-T6 to determine factors used in the conventional external pressure design formula. Assuming the outer shell to be a tube, UG31 of the Code can be used to determine the t/D_o ratios.

From Figure UG31 of the Code:

for $p = 138$ psi

$S = 5000$ psi

$t/D_o = 0.035$

$t = 0.298$ in

Try $t = .3125$ inch (5/16 in)

To check this thickness, the following formula is used*.

For Elastic Instability (very long tube)

$$p' = \frac{1}{4} \times \frac{E}{1-v2} \times \frac{t^3}{r^3}$$

where

p' = external collapsing pressure

v = Poisson's ratio

t = thickness of shell

r = radius

$$p' = \frac{1}{4} \times \frac{9.5 \times 10^6}{.91} \times .000398$$

$$p' = 1040 \text{ psi}$$

Since the Code calls for a factor of safety of 4, the allowable Code pressure would be 260 psi. This is well above the actual pressure of 138 psi.

The capsule will be leak tested with an internal pressure difference of 145 psi before insertion into the HT-1 hole. Capsule wall stress will be

$$s = \frac{pr}{t} = \frac{(145)\ (3.94)}{.312} = 1830 \text{ psi}$$

This stress is well below the allowable stress of 6000 psi at room temperature.

*See Reference 7.9, page 319.

7.4.1.2 Hemispherical Head for Capsule Shell

The head of the capsule is a thin spherical shell designed for external pressure. The stress if calculated is as follows.*

$$S = \frac{pR}{2tE}$$

Assume $t = 3/16$ inch

$p = 138$ psi

$R = 4.16$ inch

$E = .6$ - single welded batt joint without use of backing strip

$$S = \frac{138 \times 4.16}{2 \times .1875 \times .6} = 2550 \text{ psi}$$

This stress is very low.

To check for elastic design:**

$$p' = \frac{2E}{\sqrt{3(1-v2)}}\left(\frac{t^2}{R}\right)$$

$$= 2 \times \frac{9.5 \times 10^6}{1.66} \times \left(\frac{.1875^2}{4.156}\right) = 2 \times \frac{9.5 \times 10^6}{1.66} \times .00203$$

$$= 23{,}300 \text{ psi}$$

Hence, 3/16 inch wall thickness is satisfactory.

7.4.1.3 Deflection of the Capsule

When the capsule is inserted into the HT-1 through nole, the outer end will be unsupported for a distance of 46.88 in. from the wear strips installed on the through-tube. A deflection of the capsule from the concentric centerline of the capsule and through-tube will result. To insure that the capsule will not touch the through-hole, the following calculations are presented.

* Reference 7.9, page 281.
**Reference 7.9, page 318.

Assume the capsule is fixed at the wear strip point and cantilevered to the centerline of the core. The maximum deflection resulting can be calculated from:

$$\max y = \frac{-wj}{P}\left[j\left(1 + 1/2\, U^2 - \sec U\right) + L\left(\tan U - U\right)\right]^{*}_{\text{at } X = 0}$$

where

w = weight per lineal inch (of the capsule)

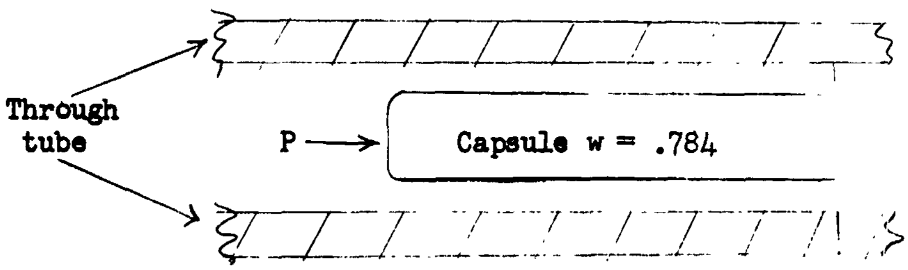
$j = \sqrt{\frac{EI}{P}}$

$U = \frac{L}{j}$

I = moment of inertia of supporting section

L = unsupported length

P = end loading on the capsule diameter to external pressure



$P = 138 \text{ psi} \times A$

$A = \frac{\pi \times 8.5^2}{4} = 56.7 \text{ inch}^2$

$P = 7830 \text{ lb}$

$I = \frac{\pi}{4}\left(r_1^{\,4} - r_2^{\,4}\right) = \frac{\pi}{4}\left(4.25^4 - 3.9375^4\right)$

$= 67.45 \text{ inch}^4$

*Reference 7.9, page 134.

$$j = \sqrt{\frac{9.5 \times 10^6 \times 67.45}{7830}} = \sqrt{81{,}800}$$

$$= 286$$

$$U = \frac{46.88}{286} = .1639 \text{ rad.} = 9.4°$$

therefore, max $y = \frac{-(.784)\ (286)}{7830}\left[286\ (1 + \frac{.1639^2}{2} - \sec .1639)\right]$

$$+ 46.88\ (\tan .1639 - .1639)$$

$$= -.0286\ (-.0143 + .0750)$$

$$= -.001734 \text{ in.}$$

This is very small and no touching will occur since the annulus is 1/4 inch.

7.4.1.4 Permanent Deformation of Capsule

To insure that no permanent deformation of the capsule will result due to the end loading, the capsule is assumed as a column fixed at the wear strip point.

$$\text{Max } S = \frac{P}{A} + \frac{Mc}{I}$$

where P = end load

A = cross-sectional area of capsule

M = moment due to cantilevered section

I = moment of inertia

C = extreme fiber distance

and *M = $-wj \left[j\ \ (1-\sec U) + L\ (\tan U)\right]$

$$= .784 \times 286 \left[286\ (1-1.01358) + 46.88\ (.1655)\right]$$

$$= .784 \times 286 \times 3.88 = -870 \text{ in-lb}$$

*See Section 7.9, page 134.

$$\text{Max } S = \frac{7830}{8.00} + \frac{870(4.25)}{67.45}$$

$$= 979 + 55$$

$$= 1034 \text{ psi}$$

This is small, compared to the yield stress of 24,000 psi; thus, no permanent deformation will result.

7.4.1.5 Capsule Back Section

The back section of the capsule is designed to withstand a pressure difference of 145 psi. The following ASME Code formula was used to determine the thickness of the back section:

$$t = \frac{pR}{SE - 0.6\ p}$$

where p = pressure = 145 psi

R = inside radius = 4.25 inch

S = allowable stress value = 17,000 psi

E = joint efficiency = 1

$$t = \frac{145 \times 4.25}{17{,}000 - 0.6 \times 138}$$

$$= .0365 \text{ inch}$$

A wall thickness of 0.3125 inch was maintained, so that the inside diameter would be the same over the length of the capsule.

The backplate is also designed to withstand 145 psi coolant water. The Code formula for flat heads and covers was used to determine the plate thickness.

$$t = d\sqrt{cp/S}$$

where d = diameter of cap = 11 inch

c = factor depending on the method of attachment = .3

p = pressure = 145 psi

S = allowable stress = 15,300 psi

$t = 11 \sqrt{.3 \times 145/15{,}300}$

$= .583$ inch

A plate thickness of 1.82 inch was selected to maintain the same type and size of joint as the capsule-to-adapter sleeve joint.

7.4.1.6 <u>Thermal Stresses in Capsule Wall</u>

<u>Axial Stresses Due to an Axial Temperature Gradient</u>

The axial temperature gradient induces an axial thermal stress, σ_{xth}.

The maximum wall temperature is determined by the heating rate and 100% heat transfer into the external water.

Assume axial conduction = 0

Taking 1 sq ft of surface at core centerline

$$\frac{Q}{A}\max = 55{,}000 \text{ BTU/hr-ft}^2 \text{ at core center*}$$

$$\frac{Q}{A} = 0 \text{ at 26 inch}$$

Let us assume the distribution is a straight line function.

h = heat transfer coefficient = 1222 BTU/hr-ft^2-°F*

$$\text{max temp} = T_{water} + \Delta T_{max}$$

$$T_{max} - \frac{Q}{Ah} = \Delta T_{max} = \frac{55{,}000}{1222} = 45.4°F.$$

*Reference Section 7.1.2.2.

At 26 inch from core centerline

$$\Delta T = 0, \ \frac{Q}{A} = 0$$

and T wall = T water

Spread over 26 inch, the linear gradient of temperature

$$= \frac{45.4}{26}\left(\frac{°F}{\text{inch}}\right) = \frac{1.74°F}{\text{inch}}$$

Axial stress* $\delta_{xth} = 0.353 \ E\alpha \sqrt{\bar{R}t} \ \frac{dT}{dx}$

where $\bar{R} = 4.25$ inch

$t = 0.3125$ inch

$E\alpha = 140$ (Al)

$$\delta_{xth} = 0.353 \times 140 \ \sqrt{4.25 \times 0.3125} \times 1.74$$

$$= 99.5 \text{ psi stress}$$

Axial Stress Due to a Radial Temperature Gradient

Let us assume an axial temperature gradient = 0. There is a thermal stress induced by the radial temperature gradient in the capsule caused by γ heating. The worst case that may be considered is that 100% of the heat produced at the highest γ heating rate (8w/g) is spread out radially.

$$\Delta T = \frac{Q}{V} \times t^2/2k$$

$$k_{Al} = 96 \text{ BTU/hr-ft}^2\text{-°F/ft}$$

*Reference Section 7.10, page 500.

$$*\Delta T = \frac{\frac{Q}{V}\max t^2}{2k}$$

where $\left(\frac{Q}{V}\right)\max = 8.0 \frac{\text{watts}}{\text{gram}} \times 454 \frac{\text{gram}}{\text{lb}} \times 0.098 \frac{\text{lb}}{\text{ft}^3} \times 1728 \frac{\text{ft}^2}{\text{in}^3}$

$$\times 3.412 \frac{\text{BTU}}{\text{hr-watt}}$$

$$= 2.09 \times 10^6 \frac{\text{BTU}}{\text{hr-ft}^3}$$

$$t = 0.312 \text{ in} = .026 \text{ ft}$$

$$k = 96 \frac{\text{BTU}}{\text{hr-ft-°F}}$$

$$\Delta T = \frac{(2.09 \times 10^6)\ (.026)^2}{2(96)}$$

$$= 7.4°\text{F}$$

$$**\ \delta xth = \frac{1}{2}\ \frac{E\alpha\Delta T}{(1-\mu)} = \frac{1}{2} \times \frac{140}{.7} \times 7.4$$

$$\delta xth = 740 \text{ psi}$$

The axial stress is low enough so that an infinite thermal cycle life can be expected.

*Reference Section 7.13, page 9-54.
**Reference Section 7.10, page 497.

7.4.1.7 Calculations of Required Thickness of Experiment Piping

Three inch piping required thickness (austenitic stainless steel) from Section 1 of ASME Code (no corrosion allowance):

$$t_{inch} = \frac{P \times D}{2S \times 2yP}$$ where piping is austenitic stainless steel*

and $P = 138$ psi

$D = 3.5$ inch

$S = 17000$ psi

$y = 0.4$

$$t = \frac{138 \times 3.5}{2 \times 17000 + 2 \times 0.4 \times 138} = 0.0148 \text{ inch required thickness}$$

Thickness of Schedule 10 pipe = 0.120 inch

Ten inch Schedule 40 pipe sleeve (austenitic stainless steel) (no corrosion allowance):

$$^{*}t = \frac{P \times D}{2S + 2yP}$$

where $P = 138$ psi

$D = 10.75$ inch

$S = 17000$

$y = 0.4$

$$t = \frac{138 \times 10.75}{2 \times 17000 + 2 \times 0.4 \times 138} = 0.0504 \text{ inch required thickness}$$

Thickness of Schedule 40 pipe = 0.365 inch

Unitrace - no pressure difficulties.**

* Reference Section 7.11, page 247, 250
**Reference Section 7.12.

8.0 HAZARDS ANALYSIS

8.1 MAXIMUM CREDIBLE ACCIDENT

From the hazards evaluation of the capsule and experiment, the maximum credible accident has been determined to be the complete severance of the capsule piping below the level of the quadrant water. This accident is analyzed in Section 8.3.

Extremely pessimistic assumptions were made to indicate the time allowed for an operator to provide emergency coolant flow. This time was in excess of 10 minutes, at which time the contained stagnant water would rise to less than 180°F. This is well below the 235°F saturation temperature corresponding to the head of the quadrant water.

The following assumptions were made to obtain the foregoing results:

1. Flow stops completely in HT-1 and capsule. Flow stoppage in any one line will allow pressure relief through the other paths.

2. Reactor scrams and gamma heating drops to 39.2 percent of original level and decays as shown in Figure 8.1.

3. There is no heat transfer to HT-1.

4. There is no heat sink capacity of the metal components.

5. Mean water temperature prior to accident is 144°F. (Refer to Section 7.1).

6. PC water continues to flow through the beryllium.

For the maximum credible accident, it is now assumed that the operator does not manipulate the emergency cooling valves in time. It will be shown that the heat generated in the system ten minutes after the accident can be removed by transfer through the HT-1 wall, without damage to the HT-1 or the capsule.

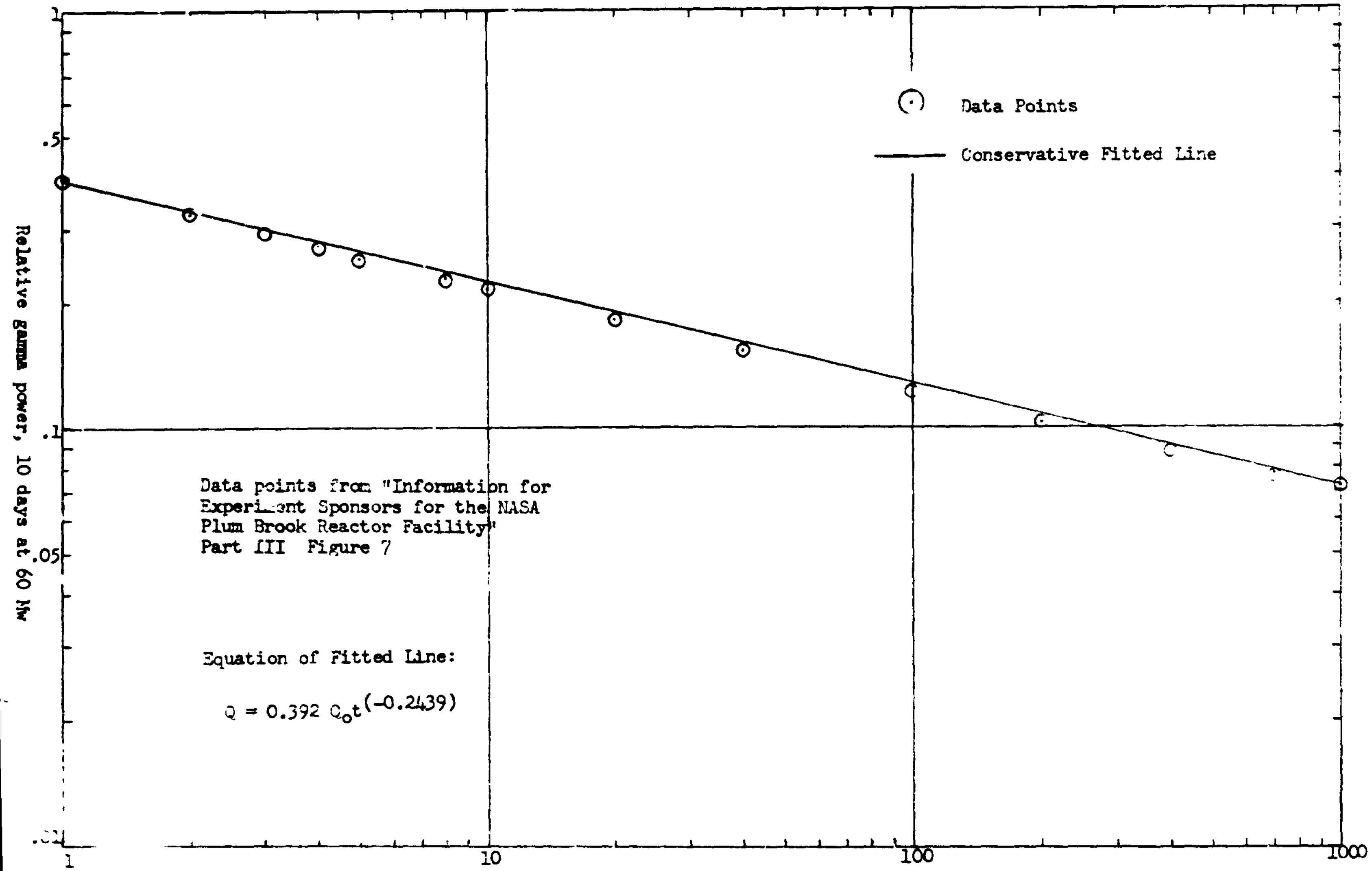


Figure 6.1 Gamma Heating Decay Curve

Assuming thermal equilibrium at this flow rate and heat generation, the enthalpy of the outlet water is:

$$h_{(out)} = h_{in} + Q/\dot{m}$$

$h_{(out)}$ = Outlet enthalpy, BTU/lb

h_{in} = Inlet enthalpy, BTU/lb = 103 BTU/lb at 135°F

Q = Heat generation rate, BTU/hr = 272,600 BTU/hr

$\dot{m}$ = Flow rate, lb/hr = 1840 lb/hr

$$h_{(out)} = 103 + 272{,}600/1840 = 251.2 \text{ BTU/lb}$$

From standard steam tables, the temperature corresponding to the outlet enthalpy of 251.2 BTU/lb is 281.8°F.

Thus, assuming shutdown cooling and the maximum shutdown gamma heating rate, the bulk coolant does not attain saturation temperature.

8.2.2 Maximum Capsule Wall Temperature

To determine the maximum capsule wall temperature, the assumption is made that the worst condition occurs in the 6 inch segment of the capsule containing the test fixture, for which 75 percent of the internal heating is removed through the capsule wall at the sample centerline (maximum heating).

Heat is supplied to the water, prior to reaching the core midplane, as listed below. Data on full-power heating rates is taken from Section 7.1:

Half of water = 1/2 x 377,900	= 188,950 BTU/hr
Half of HT-1 = 1/2 x 136,000	= 68,000
Hemispherical head	= 11,500
Capsule, to midplane = 3/4 x 24,000	= 18,000
Sample, to midplane = 3/4 x 1/2 x 60,800	= 22,800
Total heat to midplane	309,250 BTU/hr

$$A = \frac{\pi}{4}\left[\left(\frac{9}{12}\right)^2 - \left(\frac{8.5}{12}\right)^2\right] = .04772 \text{ ft}^2$$

$$G = 1840/.04772 = 38,560 \text{ lb/hr-ft}^2$$

μ = Viscosity, lb/hr-ft = .6897 lb/hr-ft at 200°F (data from Reference 8.2, page 466)

$$N_{Re} = \frac{0.04167 \times 38,560}{0.6897} = 2,330$$

The flow is therefore laminar or transition type flow. Since the heat transfer coefficient for laminar flow is the smaller, the calculation will be based on laminar flow.

Reference 8.2 gives a correlation for heat transfer on page 232. The equation is:

$$\frac{hD}{k} = 1.75 \left(\frac{WC_p}{kL}\right)^{1/3}$$

which can be rearranged to solve for h:

$$h = 1.75 \left(\frac{WC_p}{kL}\right)^{1/3} \frac{k}{D} \quad \frac{\text{BTU}}{\text{hr-ft}^2}$$

h = Heat transfer coefficient, BTU/hr-ft^2

w = Weight flow, lb/hr = 1840 lb/hr

C_p = Specific heat at constant pressure, BTU/lb-°F = 1.01 BTU/lb-°F at 200°F (Data from Reference 8.2, page 462)

k = Thermal conductivity, BTU/hr-ft-°F = 0.393 BTU/hr-ft-°F at 200°F (Data from Reference 8.2, page 456)

L = Length of heated section, ft = 6/12 ft

The design of HT-1 is such that all the heat generated at full reactor power by the empty HT-1 tube can be removed by the primary coolant flowing on the outside. Using this statment, the minimum overall heat transfer coefficient can be computed by making the following assumptions:

1. HT-1 temperature = 300°F
2. Peak gamma heating = 8 watts/g
3. Primary coolant water temperature = 135°F

Heat flux through the HT-1 = $\dfrac{\text{Heat generation per unit length}}{\text{Surface area per unit length}}$

$$\frac{Q}{A} = \frac{\gamma_c \rho (V/L) \times 454 \times 3.412}{(A_s/L)}$$

γ_c = Peak gamma heating, watts/g = 8 watts/g

ρ = Density, lb/ft^3 = 169 lb/ft^3

(V/L) = Volume per unit length, ft^3/ft = $(\pi/4)\,(D_o^2 - D_i^2)$

D_o = Outer diameter of HT-1, ft = 10/12 ft

D_i = Inner diameter of HT-1, ft = 9/12 ft

$$\frac{V}{L} = \frac{\pi}{4}\left[\left(\frac{10}{12}\right)^2 - \left(\frac{9}{12}\right)^2\right] = 0.10363 \text{ ft}^3/\text{ft}$$

(A_s/L) = Surface area per unit length, (ft^3/ft) = πD_o = 2.6180 ft^2/ft

454 = Conversion factor, g/lb

3.412 = Conversion factor, BTU/watt-hr

$$\frac{Q}{A} = \frac{8 \times 169 \times 0.10363 \times 454 \times 3.412}{2.6180} \quad \frac{\text{BTU}}{\text{hr-ft}^2}$$

$$= 82{,}900 \text{ BTU/hr-ft}^2$$

The heat transfer coefficient $h = (Q/A)/\Delta T$

Q/A = Heat flux, BTU/hr-ft^2 = 82,900 BTU/hr-ft^2

Δt = Temperature difference, °F = 165°F

$$h = \frac{82,900}{165} = 502 \ \frac{BTU}{hr\text{-}ft^2\text{-}°F}$$

To determine the HT-1 wall temperature and capsule wall temperature at the end of 10 minutes, the heat flux is calculated. Heat from the capsule, sample, and HT-1 are all assumed transferred out through the HT-1.

Heat generation in capsule per unit length = $Q_c = \gamma_c \rho (V/L) \times 454 \times 3.412 \ \frac{BTU}{hr\text{-}ft}$

$$V/L = (\pi/4)\ (D_o^2 - D_i^2)$$

$$= \frac{\pi}{4} \left[\left(\frac{8.5}{12}\right)^2 - \left(\frac{7.875}{12}\right)^2 \right] = 0.5582 \ \frac{ft^3}{ft}$$

$$Q_c = 8 \times 169 \times .05582 \times 454 \times 3.412 = 116,905 \ \text{BTU/hr-ft}$$

Heat generation in sample per unit length = $Q_s = \gamma_c\ (M/L) \times 454 \times 3.412 \ \frac{BTU}{hr\text{-}ft}$

(M/L) = Weight per unit length, lb/ft = M/L_s

M = Weight of sample, lb = 9 lb

L_s = Length of sample, ft = 6/12 ft

$$M/L = 9/(6/12) \text{ lb/ft} = 18 \text{ lb/ft}$$

$$Q_s = 8 \times 18 \times 454 \times 3.412 = 223,063 \text{ BTU/hr-ft}$$

Total heat flux through the HT-1 = $(Q_c + Q_s)/(A_s/L) + (Q/A)_{HT-1}$

Q_c = Heat per unit length of capsule = 116,905 BTU/hr-ft

Q_s = Heat per unit length of sample = 223,063 BTU/hr-ft

(A_s/L) = Surface area of HT-1 per unit length = 2.6180 ft²/ft

$(Q/A)_{HT-1}$ = Heat flux due to HT-1 = 82,900 BTU/hr-ft²

$$\frac{Q}{A} = \frac{116{,}905 + 223{,}063}{2.6180} + 82{,}900 = 212{,}800 \ \frac{\text{BTU}}{\text{hr-ft}^2}$$

At 10 minutes from scram time, the heat generation rate has decayed to 8.2 percent of its initial value of 8 watts/g and so the heat flux is : $Q/A = .082 \times 212{,}800$ BTU/hr-ft² = 17,450 BTU/hr-ft².

To transfer this flux, the required temperature difference is

$$\Delta t = \frac{Q/A}{h}$$

Q/A = heat flux, BTU/hr-ft² = 17,450 BTU/hr-ft²

h = Heat transfer coefficient, BTU/hr-ft²-°F = 502 BTU/hr-ft²-°F

$$\Delta t = \frac{17{,}450}{502} = 35\text{°F}$$

The normal primary coolant temperature is approximately 135°F; therefore, HT-1 wall temperature would be 135° + 35° = 170°F.

HT-1 is designed to withstand a 300°F operating temperature. It can therefore be concluded that the integrity of HT-1 is maintained.

HT-1 temperature is maintained at 170°F and T_{sat} corresponding to the head of the quadrant water is 235°F. The condition which will exist in the annulus between the capsule and HT-1 is sub-cooled nucleate boiling. A plot of Δt vs Q/A for saturated nucleate boiling under natural-convection conditions is given in Reference 8.1, page 9-71. In order to use this correlation the heat flux through the capsule wall is required.

$$\frac{Q}{A} = \frac{(Q_c + Q_s)}{(A_s/L)}$$

Q_c = Heat per unit length of capsule = 116,905 BTU/hr-ft

Q_s = Heat per unit length of sample = 223,063 BTU/hr-ft

(A_s/L) = Surface area of capsule per unit length $= \pi D_o$ ft^2/ft

D_o = Outer surface of capsule, ft = 8.5/12 ft

$$A_s/L = \pi(8.5/12) = 2.2254 \text{ ft}^2/\text{ft}$$

$$\frac{Q}{A} = \frac{116,905 + 223,063}{2.2254} \frac{\text{BTU}}{\text{hr-ft}^2} = 152,767 \frac{\text{BTU}}{\text{hr-ft}^2}$$

After 10 minutes, the flux is down to 8.2 percent of its initial value, or
$Q/A = .082 \times 152,767$ BTU/hr-ft^2 = 12,530 BTU/hr-ft^2

Using this heat flux, Δt is about 16°F, leading to a capsule wall temperature of

$$t_c = t_{sat} + \Delta t$$

t_c = Capsule wall temperature, °F

t_{sat} = Saturation temperature of liquid = 235°F

Δt = Temperature rise at wall = 16°F

$$t_c = 235 + 16 = 251°F$$

The 251°F is a conservative figure, as it is based on saturated nucleate boiling. Since the actual condition is subcooled nucleate boiling, the capsule wall temperature will probably be below 250°F.

The capsule is designed to withstand 300°F; therefore, the integrity of the capsule will be maintained.

The experiment in the capsule contains no fuel or other hazardous material; therefore, no hazard to the reactor or personnel can be postulated.

8.2 LOSS OF PRIMARY COOLANT PUMPS

In the event of loss of coolant flow as a result of loss of the primary coolant pumps, the primary coolant flow rate drops to 5 percent of full flow or 3.75 gpm to the experiment. The following calculations show that no boiling will occur at the maximum shutdown gamma heating rate of 39.2 percent full power heating and the reduced coolant flow, and that (a) the bulk coolant temperature does not exceed the saturation temperature (324°F), and (b) the maximum capsule wall temperature does not exceed the design temperature (300°F).

The following conditions are assumed:

Flow rate of coolant = 3.75 gpm

Maximum gamma heating rate = 39.2 percent of normal heating

Inlet coolant temperature = 135°F

Of the heat generated in HT-1 wall, half is removed through the walls of HT-1 and the remainder must be removed by the coolant flow in HT-1.

The calculations show that the rate of heat transfer is greater than the rate of heat generation; therefore, the capsule wall temperature will be less than 300°F. Under static conditions the pressure in HT-1 is 80 psig, having a T_{sat} of 324°F. It can be seen that no boiling will occur and the integrity of the HT-1 and capsule is maintained. The complexity of the sample may allow some local hot spots and subcooled nucleate boiling. However, the conservatism of the assumptions makesthis unlikely and there is no possibility of net steam generation or melting of the sample.

8.2.1 Maximum Coolant Temperature

From Section 7.1, the normal heat transferred to the cooling water is 695,400 BTU/hr. Thus, at shutdown, the maximum heating rate to the coolant will be:

$$Q = 695{,}400 \times 0.392 = 272{,}600 \text{ BTU/hr}$$

$$\dot{m} = 3.75 \frac{\text{gallon}}{\text{minute}} \times 0.13368 \frac{\text{ft}^3}{\text{gallon}} \times 60 \frac{\text{min}}{\text{hr}} \times 61.28 \frac{\text{lb}}{\text{ft}^3}$$

$$= 1840 \text{ lb water/hr}$$

At shutdown, heat rate is 39.2 per cent of the full-power heating.

$$Q = 0.392 \times 309{,}250 = 121{,}230 \text{ BTU/hr}$$

The enthalpy of the water at the midplane is

$$h_{\mathcal{L}} = h_{in} + Q/\dot{m}$$
$$= 103 + 121{,}230/1840 = 168.9 \text{ BTU/lb}$$

From the steam tables, the temperature corresponding to the centerline enthalpy of 168.9 BTU/lb is 200.8°F. This is considerably below the saturation temperature of 324°F.

To obtain the capsule wall temperature at the mdiplane, the heat flux and the film coefficient are needed. A calculation of the maximum heat flux at the midplane has been previously made in this section. The result is, at full power, and using a peak heating rate of 8 watts/g,

$$Q/A = 152{,}767 \text{ BTU/hr-ft}^2$$

At scram, assuming 25 per cent of the heat is removed internally, and taking into account that the average heating rate is 4.62 watts/g, the resulting flux is:

$$Q/A = .392 \times .75 \times (4.62/8) \times 152{,}767 = 25{,}940 \text{ BTU/hr-ft}^2$$

To determine the type of flow in the annulus between the capsule and the HT-1, Reynolds' number is calculated:

$$N_{Re} = \frac{D_e G}{\mu}$$

D_e = Equivalent diameter, ft = $D_o - D_{in}$

D_o = Outer diameter of annulus, ft = 9/12 ft

D_i = Inner diameter of annulus, ft = 8.5/12 ft

$$D_e = (9/12) - (8.5/12) = .04167 \text{ ft}$$

G = Weight flow per unit area, lb/ft^2-hr = $\dot{m}/A$

$\dot{m}$ = Weight flow, lb/hr = 1840 lb/hr

A = Cross-sectional area of annulus, ft^2 = $\frac{\pi}{4}(D_o^2 - D_i^2)$

D = Equivalent diameter of annulus, ft = 0.04167 ft

$$h = 1.75 \left(\frac{1840 \times 1.01}{0.393 \times 0.5} \right)^{1/3} \times \frac{0.393}{0.04167}$$

$$= 1.75 \times (9458)^{1/3} \times 9.431 = 1.75 \times 21.15 \times 9.431$$

$$= 349 \text{ BTU/hr-ft}^2$$

The correlation is valid for $WC_p/kL \gg 10$, which is satisfied.

The capsule wall temperature can be obtained from

$$t_c = t_b + \frac{Q/A}{h}$$

t_c = Capsule wall temperature, °F

t_b = Bulk water temperature, °F = 200.8°F

Q/A = Heat flux, BTU/hr-ft^2 = 25,940 BTU/hr-ft^2

h = Heat transfer coefficient, BTU/hr-ft^2 = 349 BTU/hr-ft^2

$$t_c = 200.8 + \frac{25,940}{349} = 275.1°F$$

Therefore, a wall temperature of less than 300°F will occur when 75 percent of the heat generated in the capsule is removed through the wall of the capsule. Since this has been determined for the gamma heating rate at shutdown, the wall temperature at any time following shutdown will be less than 275°F.

8.3 SYSTEM RUPTURE

The effects of rupturing the system will vary, depending on the location assumed for the rupture. The following sections analyze ruptures of various locations in the system.

8.3.1 Capsule Pressure Tube Inside HT-1

Rupture of pressure tube or transition joint in HT-1 is not credible since the wall is designed to withstand an external pressure of 268 psi. The maximum pressure differential across the wall during normal operation is 53 psi. If, however, a leak did occur, no loss of primary coolant would result because primary coolant is on both sides of the wall.

8.3.2 Rupture Outside HT-1

A rupture outside of HT-1 in piping or flexible lines will allow primary coolant to enter the quadrant water. Two flow meters are provided, one on the inlet line and one on the outlet line. Both flows are recorded on the same scale; therefore with no leakage, both flow recordings will be the same. Regardless of where the leak occurs, it will be recognizable as a leak rather than an instrumentation calibration shift. If a leak occurs in the flow path prior to the inlet orifice, both flow meters will show a decrease in flow rate and indicate the leak and leak location. If there is a leak in the system between the inlet and outlet orifice, the inlet flow meter reading will increase and the outlet flow meter reading will decrease. A leak in the area downstream of the exit orifice will cause both flow meter readings to increase. All three emergency conditions are easily differentiated from a calibration change which would cause one flow meter to wander while the other remains constant.

Detection of a leak of a magnitude that does not cause an alarm or scram condition will immediately be reported to the PBRF reactor supervisor and corrective action will be taken at his direction.

The worst possible occurrence would be a break or pinch in the line below the quadrant water level, since the pressure in HT-1 would drop to the static head of the quadrant water. The check valve on the capsule exit line will prevent back flow of primary coolant. Low-low flow through the capsule will cause a reactor scram. The operator will close the primary coolant inlet valve and switch to capsule emergency cooling flow.

To prevent an unsafe condition from arising, sufficient time must be available for the operator to manipulate five valves to provide emergency cooling. Any of the capsule alarms being actuated causes a "WANL capsule trouble" alarm to be actuated in the experimental control room. The cause of the scram will therefore be known immediately and an operator dispatched to investigate. A pessimistic assumption of the time involved is as follows:

Operator dispatched	0.5 min
Control room to capsule	5.0 min
Checking condition	1.5 min
Operation of five valves	2.5 min
Total	9.5 min

8.3.3 Analysis

To determine the temperature of the contained water in HT-1 at 10 minutes, the following assumptions and calculations have been prepared. It was found that in 10 minutes the water temperature was 176.4°F:

1. Flow stops completely in HT-1 and capsule.
2. Reactor scrams and gamma heating drops to 39.2 percent of original level and decays as shown in Figure 8.1.
3. There is no heat transfer to HT-1.
4. There is no heat sink capacity of the metal components.
5. Mean water temperature prior to accident, as determined from Section 7.1 = 144°F.

The volume of water can be obtained, approximately, as the volume of the HT-1, less the volume displaced by the capsule, plus the volume of water within the capsule.

$$V = (\pi/4)\, D^2\, L$$

V = Volume, ft^3

D = Diameter, ft

L = length, ft

For the HT-1, $V = (\pi/4) \times (9/12)^2 \times (187/12) = 6.8845 \text{ ft}^3$

Displaced by the capsule, $V = (\pi/4) \times (8.5/12)^2 \times (120/12) = 3.9406 \text{ ft}^3$

Within the capsule, $V = (\pi/4) \times (7.875/12)^2 \times (120/12) = 3.3824$

Total volume of water $= 6.8845 - 3.9406 + 3.3824 = 6.3263 \text{ ft}^3$

The weight of water is determined from

$$W = \rho V$$

ρ = Density of water, $\text{lb/ft}^3 = 56.66 \text{ lb/ft}^3$ at 160°F (Data from Reference 8.3, page 1843)

V = Volume of water, $\text{ft}^3 = 6.3263 \text{ ft}^3$

$$W = 56.66 \times 6.3263 = 358 \text{ lbs}$$

The heat supplied is obtained by integrating the data of Figure 8.1 from 0 to 10 minutes. The equation representing the data is

$$Q = Q_o \times 0.392\, t^{(-0.2439)}$$

Q = Heating rate at time t, BTU/sec

Q_o = Heating rate at full power, BTU/sec $= 695{,}400/3{,}600 = 193.2 \ \frac{\text{BTU}}{\text{sec}}$

t = Time after scram, sec

Integrating the expression:

$$\int_0^{600 \text{ sec}} Q\,dt = \left[\frac{0.392 Q_o}{0.7561} t^{0.7561}\right]_0^{600 \text{ sec}}$$

$$= 0.51845 Q_o \times (600)^{0.7561}$$

$$= 65.351 \times 193.2$$

$$= 12{,}630 \text{ BTU}$$

The temperature of the water after 10 minutes can be obtained from enthalpy considerations:

$$h_{10} = h_o + \int \frac{Qdt}{W}$$

h_{10} = Enthalpy at 10 minutes, BTU/lb

h_o = Enthalpy of water at scram, BTU/lb = 112 BTU/lb at 144°F

$\int Qdt$ = Heat added, BTU = 12,630 BTU

W = Weight of water, lb = 358 lb

$$h_{10} = 112 + \frac{12,630}{358} = 147.3 \ \frac{BTU}{lb}$$

The water temperature corresponding to 147.3 BTU/lb is 179.3°F. This is substantially below the saturation temperature of 325°F and so there will be no meltdown or boiling within the 10 minutes required for emergency operation.

8.4 LOSS OF POWER

Loss of electrical power to the experiment flow instruments will scram the reactor. In view of this, no excessive temperatures or hazardous situations will develop.

8.5 REACTOR EXCURSION

The experiment is contained within the HT-1 through-hole. The structural integrity of HT-1 is not affected by the insertion of the capsule; therefore, no increase in the potential hazard is postulated.

A reactor power excursion to 150% of normal power will cause the experiment primary coolant exit temperature to rise to 162.8°F* and the maximum capsule wall temperature to rise to 227 °F*. Neither of these conditions is hazardous.

8.6 BOILING

Loss of primary coolant pumps, discussed in Section 8.2, showed that the maximum capsule wall temperature is less than 300°F. The saturation temperature corresponding to the static head of the primary coolant system is 324°F. In view of this, no net steam generation will occur. Some local hot spots within the sample may allow subcooled nucleate boiling; however, condensation of the minute bubbles will take place immediately on release.

The reactor is shut down at the time of the accident. Therefore, no hazards from boiling can be postulated.

During minimum flow prior to scram operation, the calculations presented in Section 7.1.3 show the maximum capsule temperature to be 235.8 °F. The saturation temperature corresponding to the normal primary coolant pressure in HT-1 is 363°F. In view of this, no boiling will occur.

8.7 HANDLING ACCIDENT

All handling of the experiment is done while the reactor is shut down. Therefore, a handling accident will have no effect on the operation of the reactor. (For detailed procedures see Section 6.)

The procedures for handling an irradiated experiment call for purging with deionized water prior to extraction from HT-1. In this manner the fluid released into the quadrant will be deionized water. To prevent any escape of active helium, the gas system is evacuated to the reactor tank vent system.

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*See Section 7.1.4.

The sample support tube is disconnected from the instruments, gas supply, and water piping, while the sample is kept submerged under 11 ft of quadrant water. As shown in Section 7.3.2, the dose rate at the surface of the water will be only 2.24 mr/hr during this operation. The sample and sample holder tube are transported along the canal to the hot cell where the in-core activated section is removed. As shown in Section 7.3.2, a dose rate of less than 2 mr/hr is predicted at the surface of the hot cell. The only accident which can result from the handling operating is the inadvertent lifting of the sample too close to the water surface. In view of this, the area will be monitored during the handling operation.

The procedures for handling a new experiment call for re-use of the non-active end of the previous sample holder. Handling of the non-irradiated sample and holder therefore poses no hazards.

The pressure tube is inserted into HT-1 first by utilizing a dolly mounted on tracks which automatically centers the tube. The sample and holder are subsequently inserted into the pressure tube. No hazard can be foreseen in these operations.

After the system is secured, a hydrostatic pressure test is conducted to check for leaks.

8.8 INSTRUMENT FAILURE

The two experiment coolant flow instruments are the only instruments which initiate a scram. A double accident, occurring at the same time, and involving duplication of an almost incredible failure mode on each of the two instruments is required in order to postulate a possibly dangerous condition. This failure mode requires breaking of the low pressure pipe line. Occurrence of a simultaneous double accident of this sort is incredible.

All other instruments have no effect on reactor safety, and failure of these instruments would only cause experiment inconvenience.

8.9 CHEMICAL REACTIONS

The materials of construction of the WANL In-Pile Test Capsule have been limited to a relatively inert group.

Underwater systems are comprised of austenitic stainless steels and aluminum. These materials are relatively inert and are in contact with water which will not exceed 300°F.

The transition joint between stainless steel and aluminum is the only point at which corrosion may possibly occur. Work by P. O. Strom, et al* indicates that corrosion problems do not exist even at this point.

*Reference 8.4

8.10 SAMPLE BELLOWS RUPTURE

The strain gages which are to be tested are actuated by a system of expansion bellows and lever arms. To expand the bellows, helium gas pressure is used; therefore, a rupture would allow gas to enter the cooling water.

To demonstrate the effect of such an occurrence, calculations have been performed to determine the amount of helium released into the capsule water and the rate at which it is released. The amount of helium released can be greater than the weight soluble by the water in the capsule. However, it is shown that even with the pessimistic assumption that none of the helium dissolves, the change in reactivity will be less than the maximum permitted when a bubble of undissolved helium is suddenly removed from the tube.

8.10.1 Solubility of Helium in Capsule Volume

8.10.1.1 Volume of He Contained in Gas System

Volume in sample fixture = 3.37 in^3

Volume in Unitrace sample holder:

Unitrace cross section area = 0.35 in^2

Length of Unitrace = 159 in

Volume = 55.6 in^3

Volume in connecting piping = $\pi/4\ D^2L$:

ID = 0.25 in

L = 660 in

Volume = 32.3 in^3

Volume in accumulator = 70 in^3

Total Volume = 3.37 + 55.6 + 32.3 + 70 = 161.27 in^3

For conservatism use 165 in^3

8.10.1.2 Volume of He That Could Leak Into the Cooling Water

Assume rupture occurs at maximum gas pressure = 265 psia

Water Pressure = 140 psia

Density of He at STP = 0.01114 lb/ft^3*

$$\rho(\text{initial} = 265 \text{ psia, } 100^\circ\text{F}) = 0.176437 \text{ lb/ft}^3$$

$$\rho(\text{final: } 140 \text{ psia, } 100^\circ\text{F}) = 0.093212 \text{ lb/ft}^3$$

$$\Delta m = V(\rho_{\text{initial}} - \rho_{\text{final}})$$

$$= \frac{165}{1728}(.176437 - .093212) = 0.007946 \text{ lb}$$

At 4 lb He per lb mol, this is 0.0019865 lb mol He

8.10.1.3 Volume of Water in Capsule (Approximate)

$$\text{Volume of cylinder} = \frac{\pi}{4} D^2L = \frac{\pi}{4} \times 7.875^2 \times 125.5 = 6100 \text{ in}^3$$

$$\text{Volume of hemispherical head} = \frac{1}{2}\left(\frac{4}{3}\right)\pi R^3 = 128 \text{ in}^3$$

Total = 6228 in^3

2 in. Unitrace - Metal Area = 1.39 in^2

Trace Area = 0.35 in^2

Non-water area = 1.39 + 0.35 = 1.74 in^2

Non-water vol. = 1.74 x 114.75 = 199.5 in^3

Sample Volume = 9 lb at 0.1 lb/in^3 = 90 in^3

Vol. of water = 6228 - (199.5 + 90) = 5938 in^3 = 3.43 ft^3

*Reference 8.3, page 1831

$\rho(160^{\circ}F) = 61\ lb/ft^3$

Weight of water = 61 x 3.43 = 209 lb

At 18 lb H_2O per lb mol, this is 11.6 lb mol H_2O

8.10.1.4 Mass of He Soluble in Capsule Water

$mf = P/K$ (Henry's Law)

mf = mole fraction gas in solvent

P = partial pressure of gas, psia

$P = P_{tot} - P_{H_2O}$

P_{tot} = total pressure, psia = 140 psia

P_{H_2O} = vapor pressure of water, psia = 4.74 psia at 160°F

$P = 140 - 4.74 = 135.26$ psia

K = Henry's Law constant, mole fraction/psia

= 19.3×10^5 psia/mol frac. at 160°F*

mf = $135.26/19.3 \times 10^5 = 7.01 \times 10^{-5}$ (mole fraction He in H_2O)

Moles He = mf x moles H_2O

= $7.01 \times 10^{-5} \times 11.6 = 8.13 \times 10^{-4}$ lb mol He

= 32.52×10^{-4} lb He

*Reference 8.5, page 15.

The amount of helium which will escape from the accumulator is 7.946×10^{-3} lb; the amount soluble is 3.252×10^{-3} lb. Therefore, 4.694×10^{-3} lb helium (1.1735×10^{-3} mole) will be insoluble in the capsule water and will have to be dissolved by the coolant flow water.

The water flow rate is 75 gallons/minute = 611.7 lb/minute.

$$75 \frac{\text{gal}}{\text{min}} \times \frac{1 \text{ ft}^3}{7.481 \text{ gal}} \times 61 \frac{\text{lb}}{\text{ft}^3} = 611.7 \frac{\text{lb } H_2O}{\text{min}}$$

$$= 34 \frac{\text{mole } H_2O}{\text{min}}$$

The time required for the 1.1735×10^{-3} moles He to be dissolved by the flowing water can be obtained from

$$t = \frac{\text{moles helium}}{\text{mole fraction x flow rate}} = \frac{1.1735 \times 10^{-3}}{7.01 \times 10^{-5} \times 34}$$

$$= 0.49 \text{ minutes}$$

The volume occupied, at 140 psia and 160°F, by the total He escaping from the system, and by the helium which is undissolved by the capsule water, can be obtained from the density and the amount involved.

$$V = M/\rho$$

V = volume occupied

M = weight of helium = 7.946×10^{-3} lb escaped, 4.694×10^{-3} lb undissolved

ρ = density of helium = .08419 lb/ft^3 at 140 psia and 160°F

$$V = 7.946 \times 10^{-3}/.08419 = .09438 \text{ ft}^3 = 163 \text{ in}^3 \text{ (total)}$$

$$V = 4.694 \times 10^{-3}/.08419 = .05575 \text{ ft}^3 = 96 \text{ in}^3 \text{ (undissolved)}$$

8.10.1.5 <u>Reactivity Effect of Helium</u>

The worst conceivable effect of the bellows rupture is as follows:

1. The bellows ruptures and the helium leaks into the capsule water. It is postulated that the voiding of the water takes place slowly enough that the regulator rods can follow the reactivity change. However, no helium dissolves into the water.

2. The resulting bubble of helium suddenly collapses or is swept away, causing a step increase in reactivity.

The maximum volume occupied by the helium is 163 in^3. Since the volume of the HT-1 adjacent to the core is 1781 in^3*, the fraction occupied is 9.15 per cent. The entire HT-1 is worth 0.5 per cent $\Delta k/k$ on changing from voided to flooded** so voiding 9 per cent of the volume will certainly have a lower reactivity worth. The maximum positive step change in reactivity will therefore be less than the maximum permitted value of 0.5 per cent***. Pro-rating the reactivity worth over the volume, the worth of the helium bubble would be 0.046 per cent $\Delta k/k$; assuming it to be in a location whose worth is 5 times the average, the result is:

$$\text{Expected worth of He bubble} = 0.229 \text{ per cent } \Delta K/K$$

$$= 30.6¢$$

Since the assumptions are extremely conservative, it is concluded that failure of the bellows will not result in a hazardous situation.

*Reference Section 7.3.3.1.

**Reference 8.7, Part III, page 2.

***Reference 8.7, Part II, page III-10.

8.10.2 Helium Release Rate

Assuming complete failure of the bellows, the helium discharge rate will be controlled by the 1/32-inch orifice. The flow rate of a compressible fluid through an orifice is given in Crane*, p. 3-24, by

$$w = 31.50\, Y d_o^2\, C\sqrt{\rho_1 \Delta p}$$

w = flow rate, lb/min

Y = net expansion factor for compressible flow = 0.895

d_o = diameter of orifice, in. = 0.03125 in.

C = flow coefficient for orifices = 0.596

ρ_1 = density of gas upstream of orifice = lb/ft^3 = 0.176437 lb/ft^3

Δp = pressure drop across orifice, psi = 125 psi

Y and C are from Crane, pp. A-20 and A-19, respectively. ρ_1 is based on 100°F and 265 psia; water pressure is 140 psia. Gas system piping is 0.25 in. inside diameter.

$$w = 31.50 \times 0.895 \times (0.03125)^2 \times 0.596 \times\sqrt{0.176437 \times 125}$$

$$= 7.706 \times 10^{-2} \text{ lb/min} = 1.9265 \times 10^{-2} \text{ lb-mol He/min}$$

This is the maximum release rate. At this rate, it will take 7.94×10^{-3} lb/ 77.06×10^{-3} lb/min = 0.103 min or 6 seconds to leak into the cooling water. Since the flow rate drops off with pressure, the actual release time will be on the order of 12 seconds.

The water flow rate is (Section 8.10.1.4) 34 lb-mol H_2O/minute. With a mole fraction of 7.01×10^{-5}, and assuming the water to leave the capsule saturated with helium, the flowing water can dissolve helium at the rate of

$$\frac{34 \text{ lb-mol } H_2O}{\text{min}} \times 7.01 \times 10^{-5} \frac{\text{lb-mol He}}{\text{lb-mol } H_2O} = 2.383 \times 10^{-3} \frac{\text{lb-mol He}}{\text{min}}$$

*Reference 8.6.

Since the release rate is, initially, 19.265×10^{-3} lb-mol He/min, the leak rate is greater than the solution rate.

However, the amount released is extremely small (8×10^{-3} lb) over a fairly long time interval (12 seconds) and so the problem is not as severe as the postulated worst situation, from Section 8.10.1.5.

8.11 ACCIDENTAL CAPSULE EJECTION

The possibility of capsule ejection from the HT-1 through-hole was evaluated by considering the mechanisms which may cause ejection. Upon inspection of the drawings of the capsule and sample fixture, it is obvious that major mechanical failure would be required to eject either the capsule or the sample from HT-1. The mechanisms which would cause ejection require massive metal failure such as shearing bolts, destruction of Marman clamps, or massive tensile failure of the capsule tube. These failure mechanisms are not credible in the reactor-HT-1-capsule system.

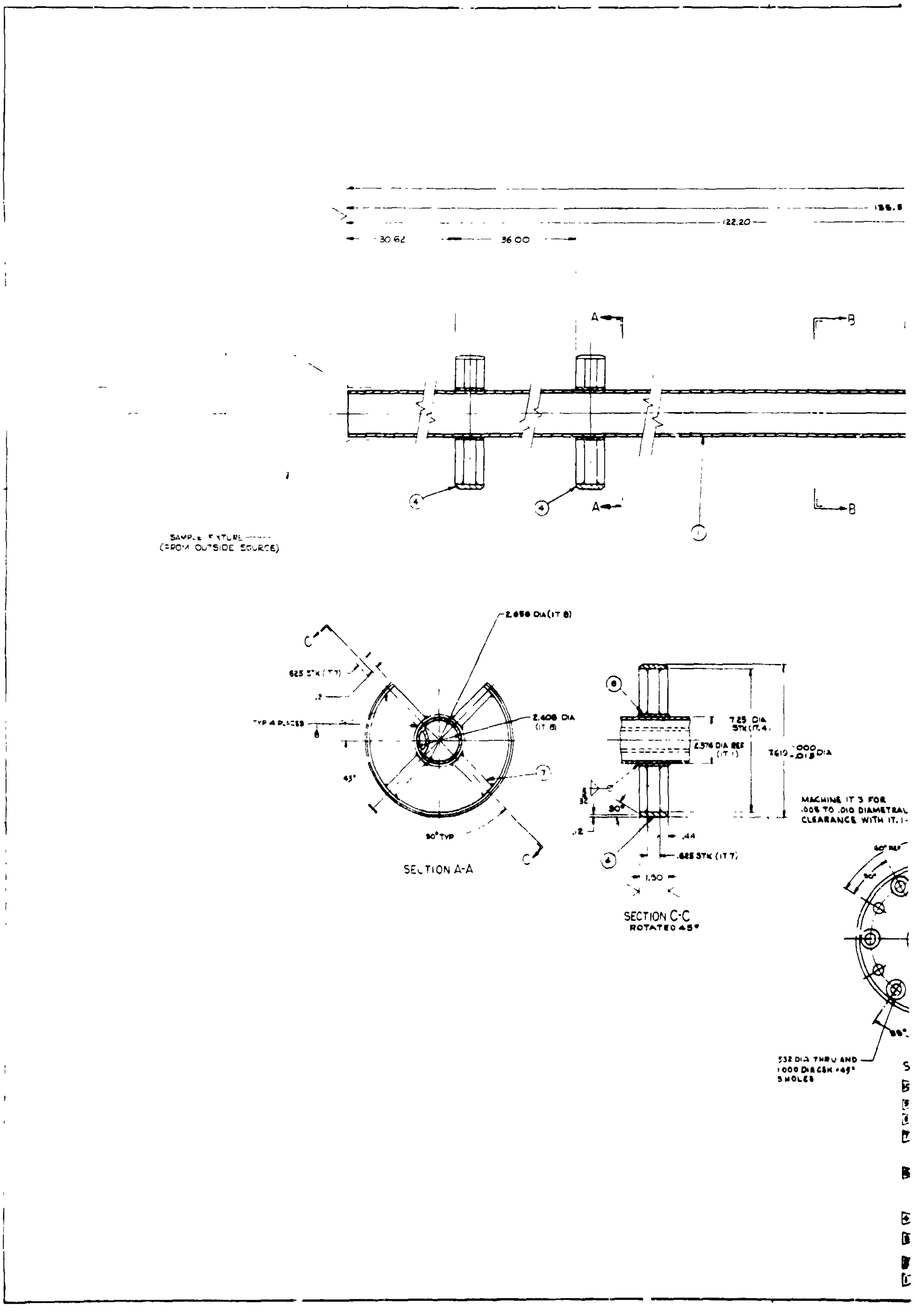
9.0 DRAWINGS

9.1 DRAWINGS INCLUDED IN HAZARDS REPORT

Dwg. No.	Revision	Title
709J928	B	Sample Holder Details and Assembly
709J929	A	HT-1 Adapter Details and Assembly
709J930	B	Capsule General Arrangement
709J931	B	Capsule Assembly (TC Layout)
566F393	-	Sample Fixture General Arrangement
566F394	G	Engineering Flow Diagram
566F395	B	Support Structure Details and Assembly
566F400	-	General Arrangement (Quadrant C)
576F011	A	Lifting Bar Details and Assembly
386D718	B	Instrument Panel Arrangement
577F041	-	Alarm and Scram Schematic
577F042	-	Wiring Diagram

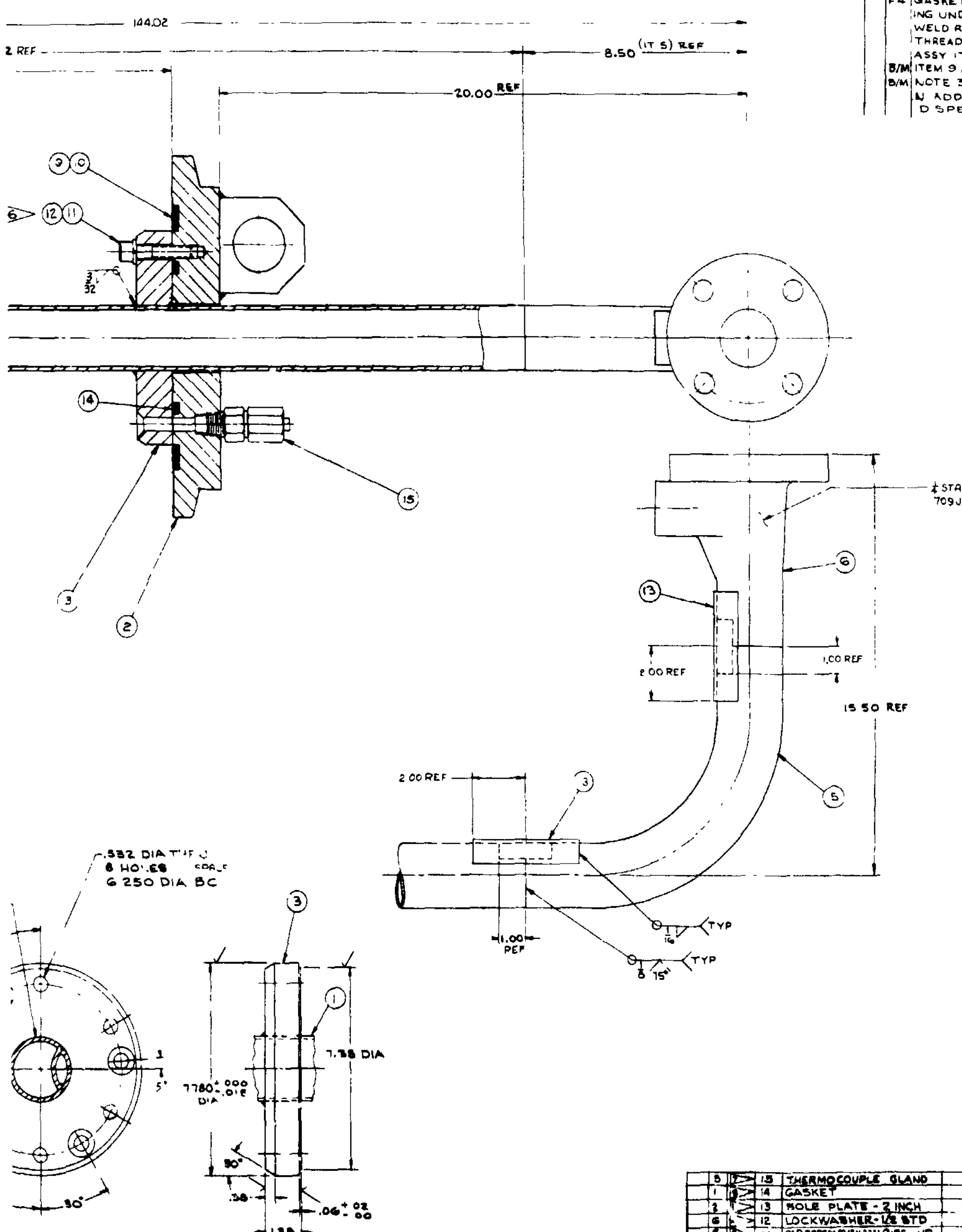
9.2 ADDITIONAL DRAWINGS FOR EXPERIMENT NOT INCLUDED IN HAZARDS REPORT

Dwg. No.	Revision	Title
566F386	A	Capsule Details and Sub-Assembly (Al)
566F387	A	Capsule Details and Sub-Assembly (SS)
566F391	B	Junction Box, Cap and Backplate Details
387D518	A	Guide Assembly
566F392	-	Sample Fixture Body Assembly
566F408	-	Sample Fixture Details and Sub-Assembly
386D719	A	Clamp Assembly
576F012	B	Wiring Layout
PF-S-12866	-	Piping Modifications
PF-S-12865	-	Equipment Mounting Modifications
709J932	A	Piping Arrangement
576F013	-	Orifice Plate and Pipe Support Details and Assembly
576F014	A	Reach Rod and Guide Plate Details and Assembly
576F015	A	Instrument Tubing Arrangement



135.5
122.20
30.62
36.00
A
B
SAMPLE FIXTURE
(FROM OUTSIDE SOURCE)
2.656 DIA (IT 8)
.625 STK (IT 7)
TYP 4 PLACES
2.406 DIA (IT 8)
45°
90° TYP
SECTION A-A
7.25 DIA STK (IT 4)
2.376 DIA REF (IT 1)
30°
.44
.625 STK (IT 7)
1.50
SECTION C-C ROTATED 45°
MACHINE IT 3 FOR .005 TO .010 DIAMETRAL CLEARANCE WITH IT 1
60° REF
.532 DIA THRU AND 1.000 DIA CSK ×45° 5 HOLES

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
A	D8	45° WAS 22°30'		
	C7	90° WAS 45°	5 24 63	
	A5	NOTE 6 WAS DRILL AND WIRE IN ACCORDANCE WITH CLASS B LOCKING SPECIFICATIONS SCREW TO BE WIRED IN PAIRS	5-29-63	
	B5	LAVA SEALANT WAS TEFLON SEALANT	6/6/63	
	B1	(ITEM 7) 6061-T6 WAS 6063-T5 D 751323-J	6-6-63	A A Stabile
B	A5	NOTE 4 WAS 7.50 ID x 9.56 OD TYPE RI	4-3-64	
	B4	TEFLON WAS LAVA" IN NOTE 7		
	D5	7.619 $^{+.000}_{-.018}$ DIA WAS 7.744 $^{+.000}_{-.018}$ DIA		
	D7	KEYWAY IT. 9 & PART OF GUIDE RING IT 4 REMOVED BETWEEN RIB QUADRANT	4-2-64	
	F4	GASKET IT 10 WAS SHOWN EXTENDING UNDER O.D. OF IT 3; 1/16 FILLET WELD REMOVED FROM AROUND THREADS OF IT 15 AT BACKPLATE ASSY IT 2	4 3-64	AA Stabile
	B/M	ITEM 9 ADHESIVE WAS KEYWAY		
	B/M	NOTE 3 DELETED FROM IT-9 & BUNA N ADDED TO IT-10 D SPEC 751323 AB DASCH 1: 5-5		



SECTION B-B

1. APPLY ADHESIVE BETWEEN METAL & RUBBER SURFACES ONLY USING CARBOLINE ADHESIVE F-1 "CARBOLINE CO" ST LOUIS MO, OR APPROVED EQUAL
2. W 2 WATER COOLED INPILE CAPSULE ASSEMBLY SPEC SECTION #1
3. 8.00 OD x .375 WALL TUBE
4. CAT NO. TG-14 ... WITH TEFLON SEALANT & 1/2 IPS MOUNTING THREAD ... FR CONAX CORP 2300 WALDEN AVE BUFFALO 25, NY OR APPROVED EQUAL
5. DRILL AND SAFETY WIRE .032 DIA 304 SS COLD DRAWN WIRE - 2 BOLTS PER WIRE
6. 7.84 ID x 9.56 OD
7. BO R FLEXITALLIC GASKET CO, CAMDEN 2, NEW JERSEY OR APPROVED EQUAL
8. 2 INCH TRACELINE TUBE
9. BO FR ALCAST FITTINGS, CLAYMONT, DELAWARE OR APPROVED EQUAL

QTY REQD	SYM	ITEM NO	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO	PART OR IDENTIFYING NO	MATERIAL	SPECIFICATION	UNIT WT	ZONE
5	▷	15	THERMOCOUPLE GLAND			CRES	AISI 303		
1	▷	14	GASKET		NO. RI-SK				
2	▷	13	HOLE PLATE - 2 INCH		NO. 20	AL	356-T7		
6	▷	12	LOCKWASHER - 1/2 STD			CRES	AISI 304		
6	▷	11	CAP SCREW .5045 x 2.25 LG SOC HD			CRES	AISI 303		
1		10	GASKET			BUNA N			
AR		9	ADHESIVE				▷		
2		8	GUIDE HUB			AL	6061-T6		
8		7	GUIDE WEB			AL	6061-T6		
1	▷	6	FLANGE - 2 INCH		NO. 200	AL	356-T7		
1	▷	5	ELBOW - 2 INCH 90°		NO. 90	AL	356-T7		
2		4	GUIDE RING		▷	AL	6061-T6		
1		3	TRANSITION PLATE			AL	6061-T6		
1		2	BACKPLATE ASSY		566F391 GR2				
1	▷	1	SAMPLE HOLDER		▷	FL	6063-T5		

LIST OF MATERIALS

INFORMATION CATEGORY	UNCLASSIFIED
AUTHORIZED CLASSIFIER	JC Bender
DATE	4-3-64

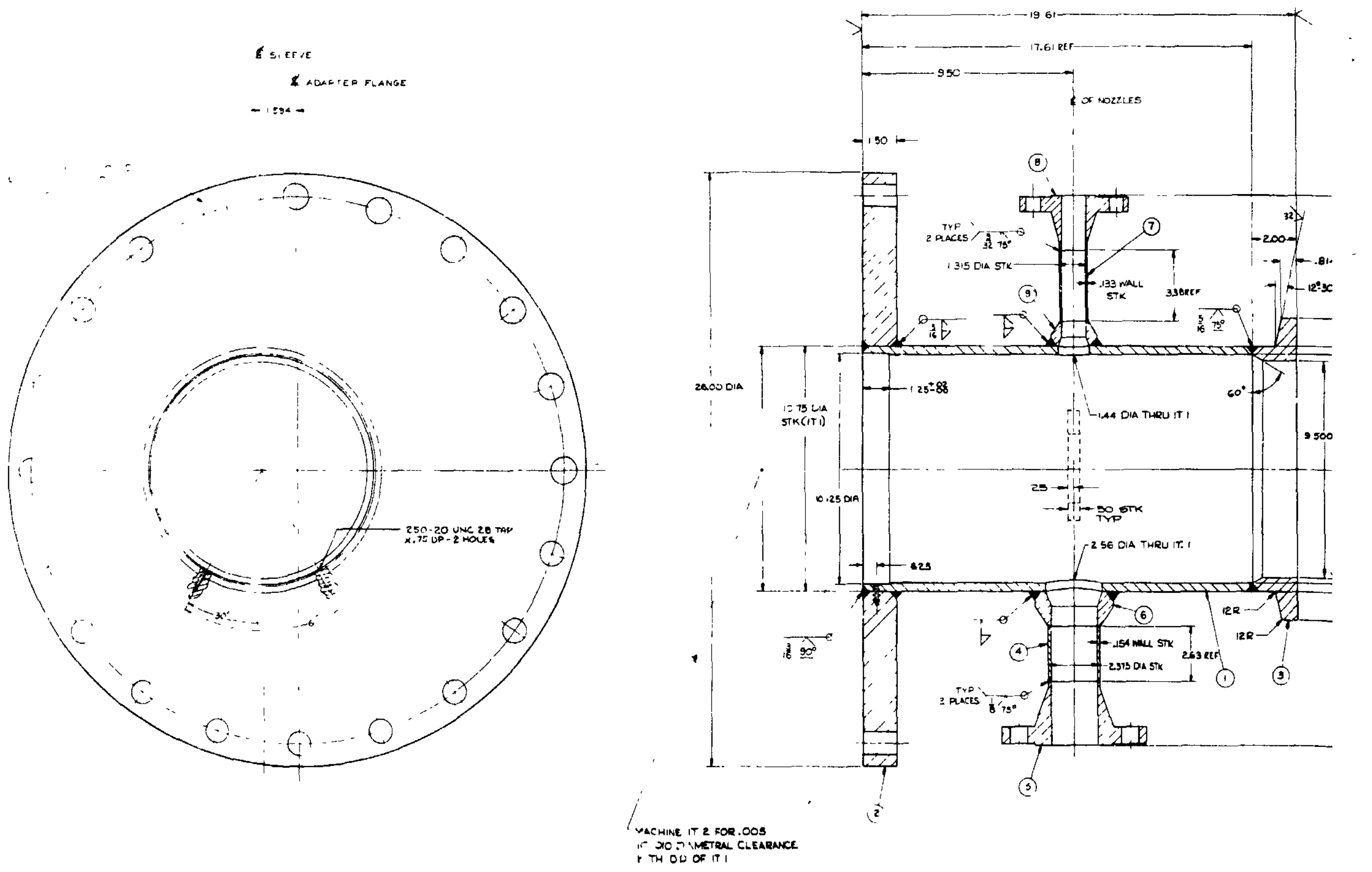
▷	GENERAL	DRTN SIMPSON	4-17-63
P294517	PART IDENT	CHECKED Fred Dorman	5/6/63
P294506-1	MFG INFO	DESIGN	5/4/63
SPECIFICATION	TYPE	ANALYSIS	
D SPEC 751323 E	PRL NO.	MATL	
		RELIAB	
		MFG	5/4/63
		A A Stabile	5-6-63
		A C	5/4/63

WESTINGHOUSE ELECTRIC CORPORATION — Astronuclear Laboratory, PITTSBURGH, PA

W 2 WATER COOLED INPILE CAPSULE
SAMPLE HOLDER DETAILS & ASSY

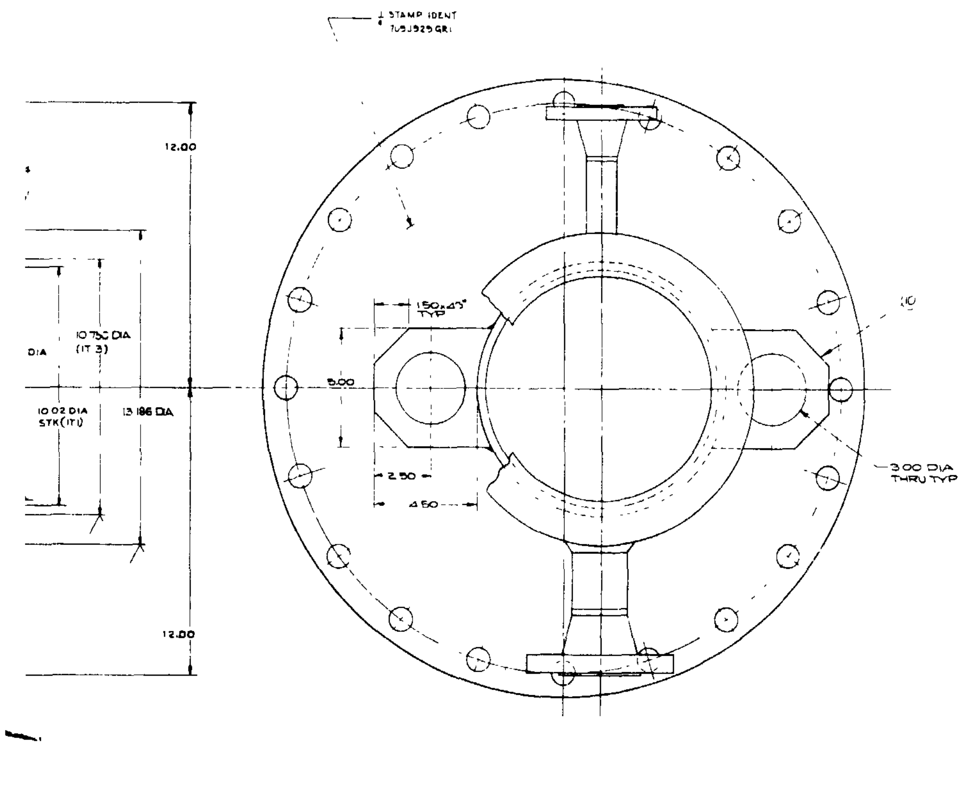
CODE IDENT NO 14683 | DWG SIZE J | DWG NO 709J328

SCALE 1/2 | WT ACT | WT CAL | SHEET 1 OF 1



ADAPTER FLANGE
250-20 UNC 2B TAP
X.75 DP - 2 HOLES
19.61
17.61 REF
9.50
OF NOZZLES
1.50
TYP
2 PLACES
1.315 DIA STK
.133 WALL
STK
3.38 REF
2.00
26.00 DIA
10.25 DIA
1.44 DIA THRU IT 1
60°
9.500
.25
.50 STK
TYP
2.56 DIA THRU IT 1
.625
12R
.154 WALL STK
2.375 DIA STK
2.63 REF
MACHINE IT 2 FOR .005
DIAMETRAL CLEARANCE

REVISIONS				
	ZONE	DESCRIPTION	DATE	APPROVED
A	G-8	√ WAS 63	5 28 63	
A	D-4	ITEM 10 ADDED	GROSH	
A	B-1	ITEM 5 6 8 AND 9 LETTER L ADDED AFTER 304		
A	E7	3.38 REF WAS 3 2 REF		
A	A 4	NOTES 2 & 3 WERE 300 LB PART NO 30		
A	C 7	2.65 REF WAS 2.38 REF		
A	F 3	DRILL [illegible] TAP X 1.25 DEPTH	6-5-63	
A	D 10	ADDED .250 20 TAP 2 HOLES		
A	D 8	ADDED .25 DIM		
A	D	ADDED 30° & 60° D 751323-M	6/6/63	A A Stabler



7 W-2 WATER COOLED INPILE CAPSULE ASSEMBLY SPEC SECTION #1

6 10X1 SCH 40

5 10X2 SCH 40

4 B.O FR BONNY FORGE & TOOL WORKS, ALLENTOWN, PA., OR APPROVED EQUAL

3 1 INCH 150 LB PART NO. 15

2 2 INCH 150 LB PART NO. 15

1 BO FR LADISH CO, CUDAHY WISCONSIN OR APPROVED EQUAL

QTY REQD	SYM	ITEM NO	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO	PART OR IDENTIFYING NO	MATERIAL	SPECIFICATION	UNIT WT	
2		10	LIFTING EYE			CRES	AISI 304 L		
1	6	9	WELDOLET		2	CRES	AISI 304L		
1	5	8	WELDING NECK FLANGE		1	CRES	AISI 304L		
1		7	PIPE 1.00 SCH 40			CRES	AISI 304L		
1	4	6	WELDOLET		2	CRES	AISI 304L		
1	4	5	WELD NG NECK FLANGE		3	CRES	AISI 304L		
1		4	PIPE 2.00 SCH 40			CRES	AISI 304L		
1		3	CLAMP FLANGE			CRES	AISI 304L		
1		2	ADAPTER FLANGE			CRES	AISI 304L		
1		1	PIPE 10.00 SCH 40			CRES	AISI 304L		

LIST OF MATERIALS

INFORMATION CATEGORY
UNCLASSIFIED
AUTHORIZED CLASSIFIER / DATE

7 GENERAL
P294917 PART IDENT
P294500 MFG INFO
SPECIFICATION / TYPE
D SPEC 751323-E / REL NO.

DRAWN SIMPSON 4-10-63
CHECKED 8/6/63
MATERIALS
DESIGN 5/4/63
RELIABILITY 5/4/63
PROJECT APPR 709 [illegible]

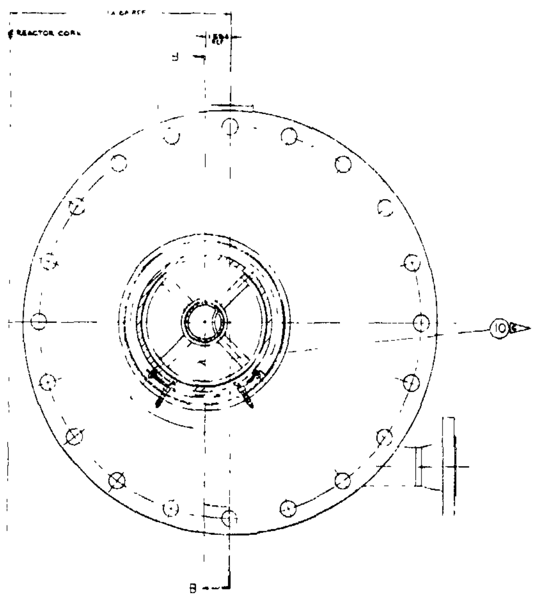
WESTINGHOUSE ELECTRIC CORPORATION
Astronuclear Laboratory PITTSBURGH, PA

W-2 WATER COOLED INPILE CAPSULE
HT-1 ADAPTER DETAILS & ASSY

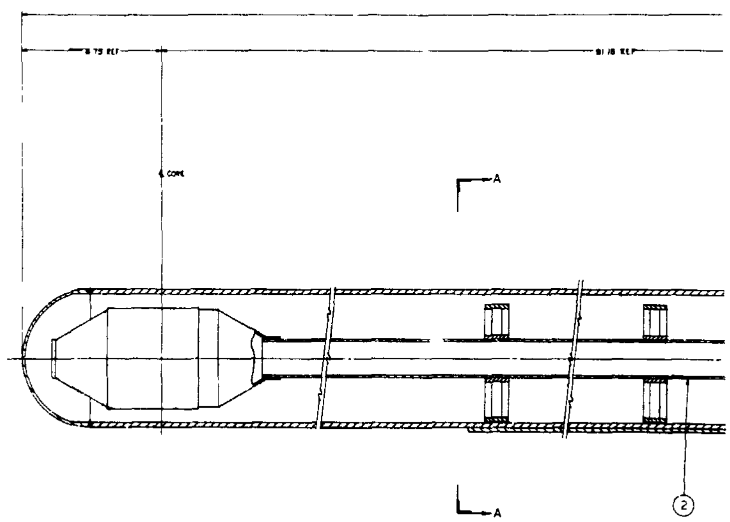
CODE IDENT NO 4583 | DWG SIZE J | DWG NO 709J929
SCALE 1/2 | SHEET 1 OF 1

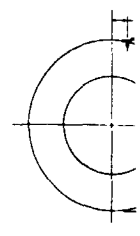
709J929 SHEET 1

2

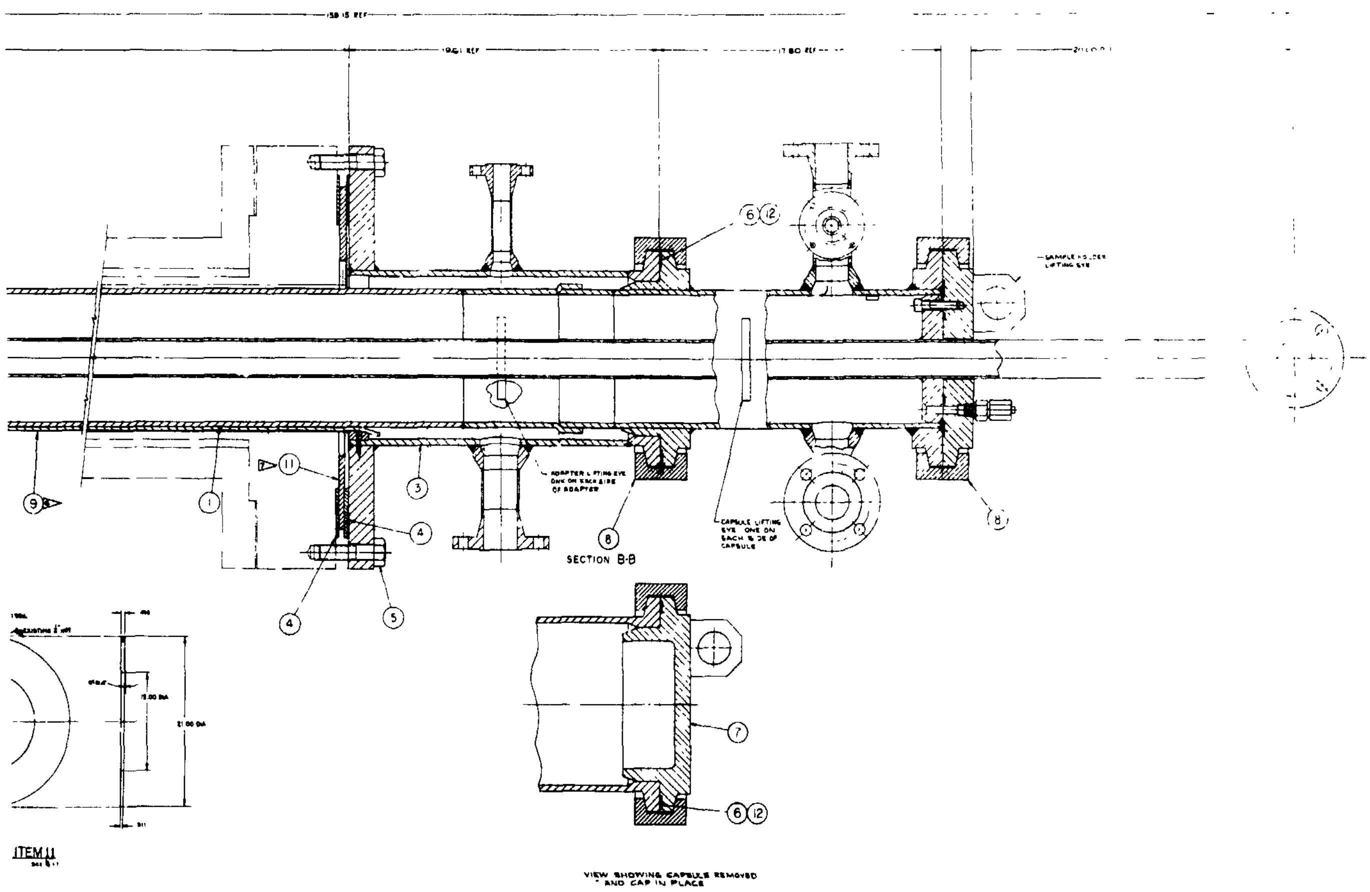


SECTION A-A





DETAIL



APPLY ADHESIVE BETWEEN METAL & RUBBER SURFACES ON 4 USING CARBOLINE ADHESIVE P-1 CARBOLINE CO ST LOUIS MO, OR APPROVED EQUAL

FABRICATE TO SUIT CAPSULE ALIGNMENT WITH IT 2

PEEN C BORE HOLE IN IT 9 OVER HEAD OF IT 10 AT ASSEMBLY TO PREVENT IT 10 FROM BACKING OUT TYP 2 PLACES

W-2 WATER COOLED INPILE CAPSULE ASSEMBLY SPEC

MARMAN DIVIS ON AEROQUIP CORP LOS ANGELES CALIF OR APPROVED EQUAL

BOLT TO BE CHROME PLATED

12.75 OD

PART FLEXATALLIC GASKET CO CAMDEN NEW JERSEY OR APPROVED EQUAL

	12	ADHESIVE		
1	11	WEDGE PLATE	CRES	AISI 304
2	10		CRES	AISI 303
1	9	GUIDE ASSY		
1	8	CLAMP	CRES	AISI 304
1	7	CAP		
	6	GASKET		
	5	BOLT	CRES	AISI 303
1	4	GASKET	CRES	AISI 304
1	3	HT / ADAPTER ASSY		
1	2	SAMPLE HOLDER ASSY		
1	1	CAPSULE ASSY		

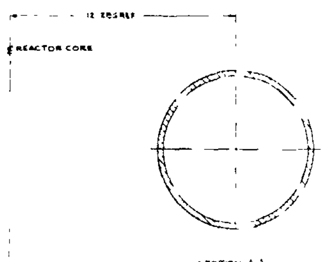
LIST OF MATERIALS

UNCLASSIFIED

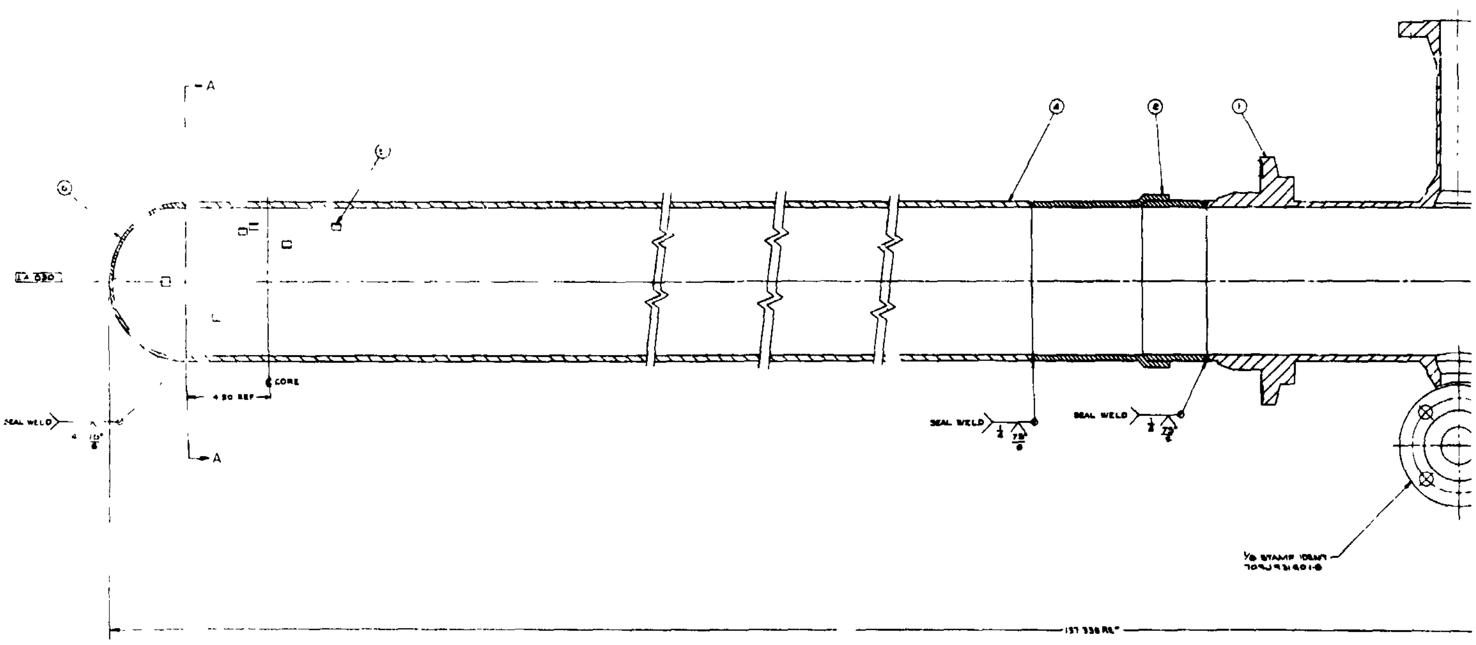
W-2 WATER COOLED INPILE CAPSULE GENERAL ARRANGEMENT

4683 J 709J930

2

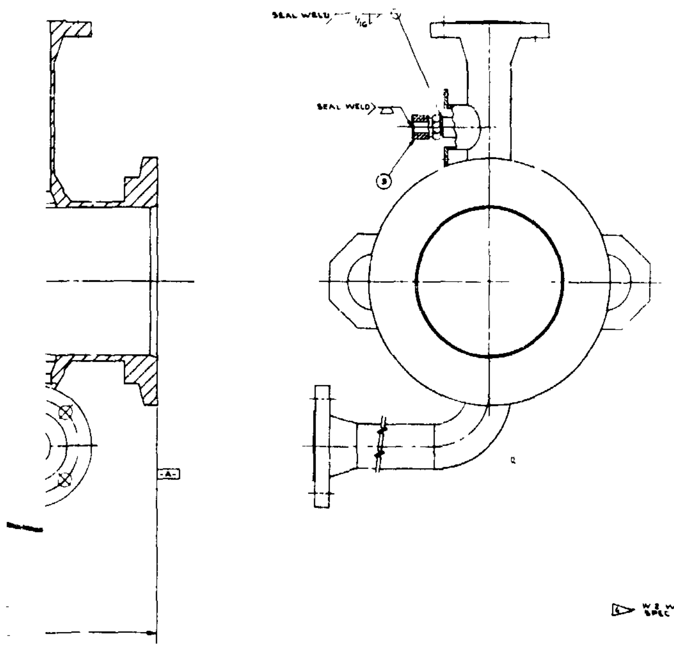


SECTION A-A



REVISIONS

A	E-5	SHORTENED FLANGE 2 84.	7-1[illegible]	
	C-2	CHANGED LOCATION OF BOLT HOLES OF FLANGE TO STRADDLE ℄s		
	E-5	ROTATED CAP ASSY, 180°		
	A-5	NOTE 4 WAS: DRILL AND WIRE IN ACCORDANCE WITH CLASS B LOCKING SPECIFICATIONS. BOLTS TO BE WIRED IN PAIRS		
	A 5	NOTE 3 LAVA SEALANT WAS TEFLON CHG'D ITEM 4 AS REQ'D BY DETAIL. IT 4 [illegible] WAS [illegible] IT 6 [illegible] WAS [illegible] D-781[illegible]-J		
		CHANGE ITEM 4 TO CONFORM WITH DETAIL. IN B/M IT 6 CAPSULE BODY 866F386H01 WAS CAPSULE BODY ASSY 866F386 G01 IN B/M IT 6 866F386H02 WAS 866F386H03 [illegible] 129-M		
B	E6	[illegible] OF CONAX FITTING & WIRE REMOVED EIGHT TC'S & RELATED DIMS REMOVED NOTES 4 & 5 REMOVED IN NOTE 3 'WITH LAVA SEALANT' REMOVED		
	B/M	IT 3 WAS INSTRUMENT LEAD GUIDE ASSY & ITS 9,10,11 & 12 REMOVED		
	B12	[illegible]		



1. W2 WATER COOLED INPILE CAPSULE ASSEMBLY SPEC SECTION #1

2. CAT NO. TG-16-A8 & 500 IPS MOUNTING THREAD SO FR CONAX CORP 2300 WALDEN AVE BUFFALO 25, NY OR APPROVED EQUAL

3. 8 INCH BI-BRAZE TRANSI-JOINT SO FR ARTHUR TICKLE ENGINEERING WORKS, INC 21 DELEVAN ST BROOKLYN 31, NY PER DWG NO. C-150 OR APPROVED EQUAL

4. .625 DIA × 1.00 LG

8	CAP ASSY		
7	[illegible] GLAND		AISI 303
	[illegible] HEAD		
	[illegible]		
4	[illegible] BODY		
	[illegible]	CRES	AISI [illegible]
	[illegible] JOINT		
	[illegible] ASSY		

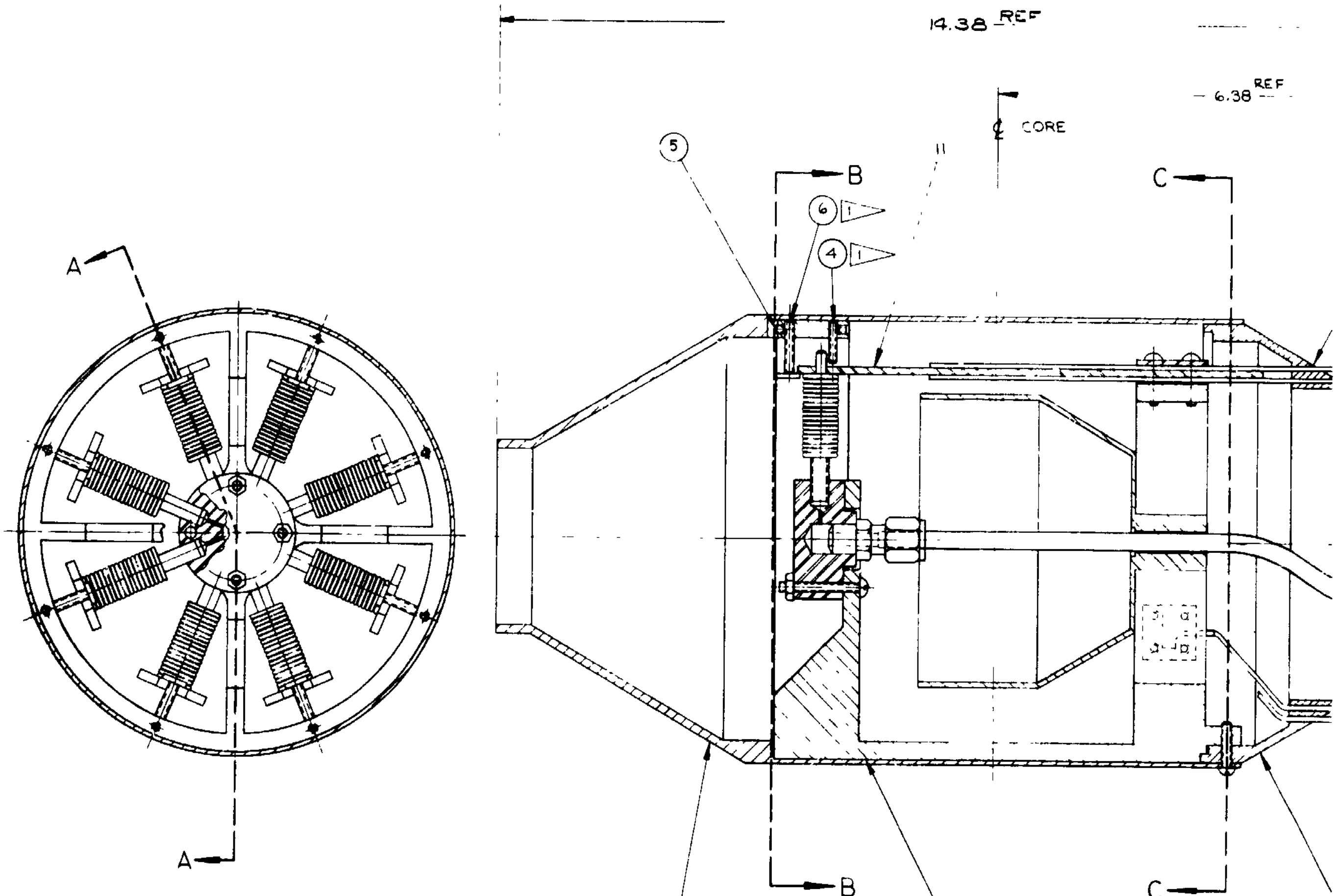
LIST OF MATERIAL

INFORMATION CATEGORY
UNCLASSIFIED

W2 WATER COOLED INPILE CAPSULE
CAPSULE ASSEMBLY

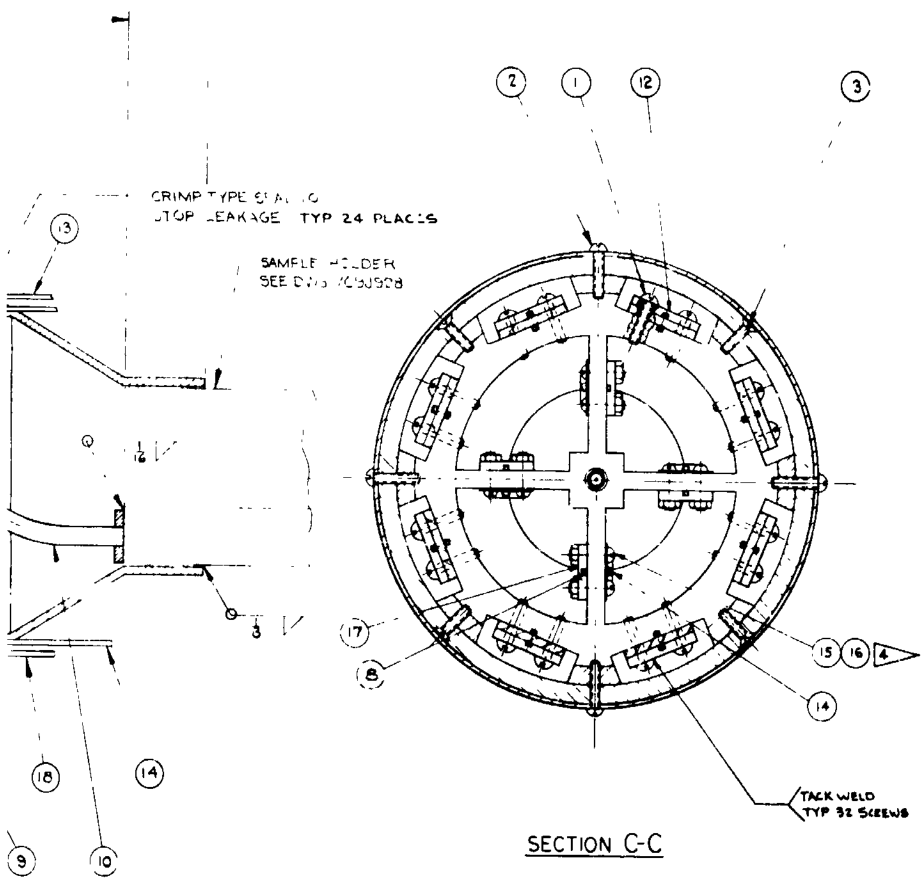
H I 709J931

7



SECTION B-B

SECTION A-A



SECTION C-C

QTY REQD	SYM	ITEM NO.	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO.	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	UNIT WT.	ZONE
4		18	THERMOCOUPLE						
4		17	CLAMP		566F408H15				
16		16	.112-40 UNC-2B HEX NUT			ALUM	2024-T4		
16		15	.112-40 UNC-2A X .50 LG RD HD MACH SCREW			ALUM	2024-T4		
4		14	TEMPERATURE TRANSDUCER						
16		13	STRAIN GAGE						
8		12	CLAMP		566F408H14				
8		11	BEAM		566F408H16				
1		10	AIR LINE ASSY		566F408G05				
1		9	REDUCER		566F408H13				
1		8	BODY ASSY		566F392G01				
1		7	COVER ASSY		566F408G01				
8		6	ADJUSTMENT SCREW ASSY		566F408G04				
16	3	5	.112-40 UNC-2A X .375 LG RD HD MACH SCREW			ALUM	2024-T4		
8	2	4	.112-40 UNC-2A X .625 LG RD HD MACH SCREW			ALUM	2024-T4		
4		3	.138-32 UNC-2A X .50 LG FLAT HD MACH SCREW			ALUM	2024-T4		
4		2	.138-32 UNC-2A X .625 LG RD HD MACH SCREW			ALUM	2024-T4		
32		1	.138-32 UNC-2A X .625 LG RD HD MACH SCREW			ALUM	2024-T4		

LIST OF MATERIALS

DRAWN GREGORIO 5-17-63
CHECKED 6-3-63
6-3-63
MATERIALS
DESIGN

WESTINGHOUSE ELECTRIC CORPORATION
Astronuclear Laboratory
PITTSBURGH, PA.

W-2 WATER COOLED INPILE
CAPSULE-SAMPLE FIXTURE
GENERAL ARRANGEMENT

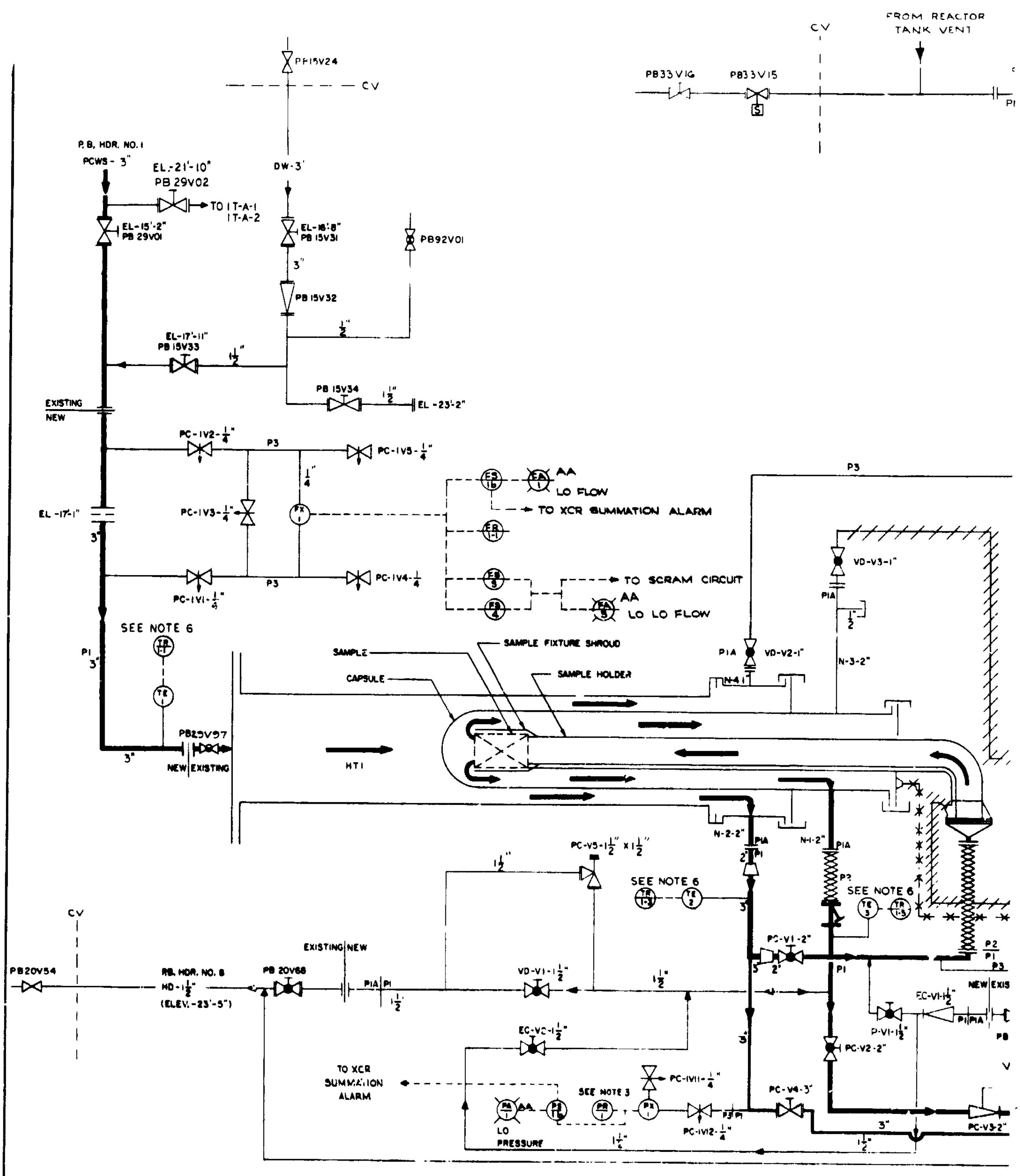
CODE IDENT NO. 14683 | SIZE F | DWG NO. 566F393

SCALE 1/1 | WT ACT | WT CALC | SH 1 OF 1

P294506 MFG INFO

751323-E

2

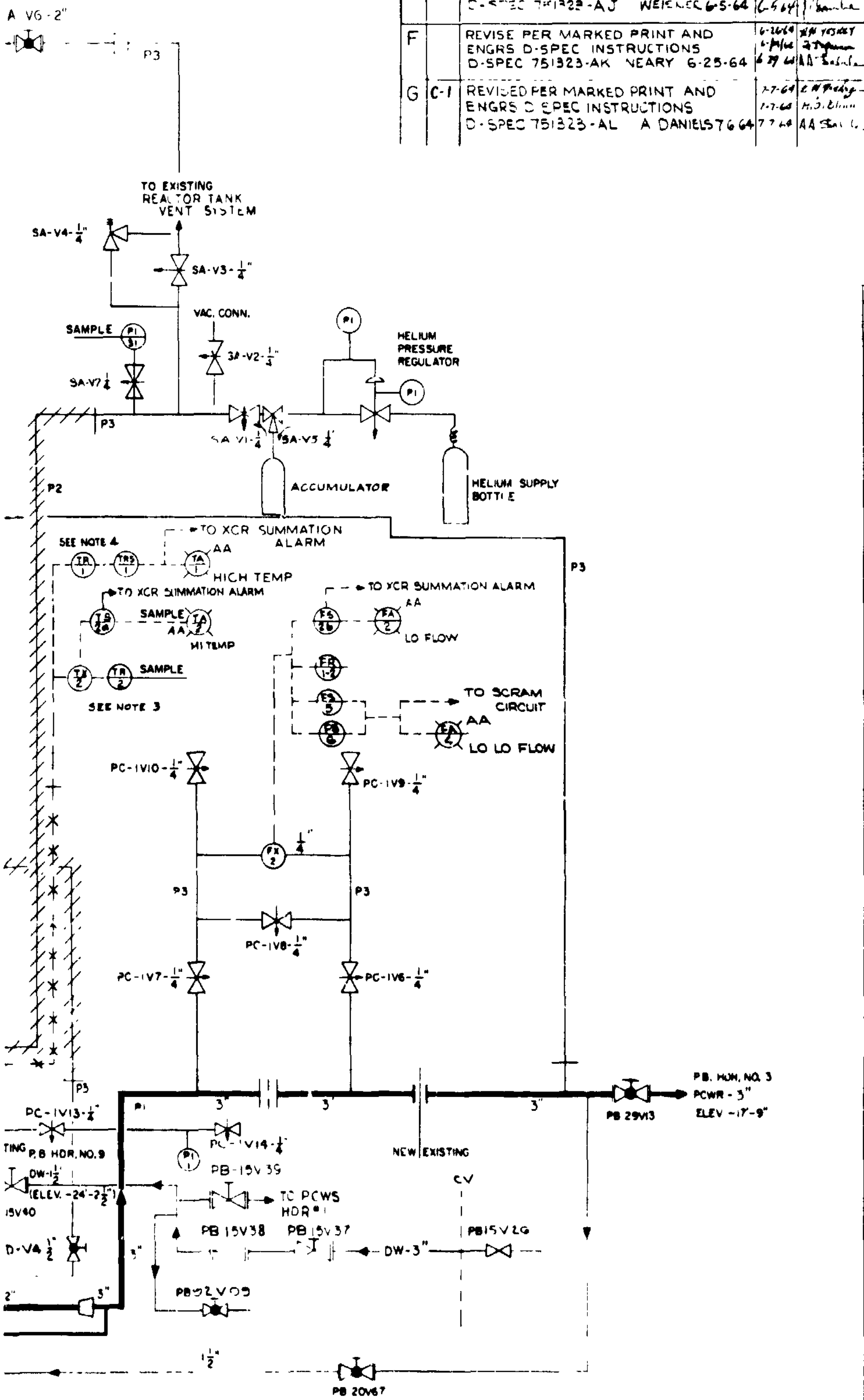


6 POI
5-SLT
4-INCL
3-PRI
2-REFE
1-SAMPL
EXPE

	ZONE			
E		REVISE PER MARKED PRINT AND ENTER D-SPEC INSTRUCTIONS. D-SPEC 751323-AJ WEISNER 6-5-64	6-5-64 / 6-5-64	A A Stehle
F		REVISE PER MARKED PRINT AND ENGRS D-SPEC INSTRUCTIONS D-SPEC 751323-AK NEARY 6-25-64	6-26-64 / 6-29-64	
G	C-1	REVISED PER MARKED PRINT AND ENGRS D-SPEC INSTRUCTIONS D-SPEC 751323-AL A DANIELS 7-6-64	7-7-64 / 7-7-64	AA Stehle

REVISIONS

SYM	ZONE	DESCRIPTION	DATE	APPROVED
A		REVISED IN ... C-3 B4 CORRECTED LEGEND PER ENGINEERING REQUEST ADDED NOTES 5 & 6 D SPEC 751323 J ... 3 63 ADDED 3-WAY VALVE & ACCUMULATOR 3 LINE WAS 1½" IN ZONE 5-B, 5-C, 5D ADDED 3 X 2 REDUCERS ADDED PB15V37, PB15V38, & PB15V39 VALVES D-SPEC 751323-J D GERNHARDT 6-7-63	5 31 63 / 6-7-63	A A Stehle
B		REVISED TO AS BUILT CONDITION D-SPEC 751323-S J REED 9-27-63	10-1-63	
C		REVISED TO AS BUILT CONDITION D-SPEC 751323-AB H MARKS 12-3-63	12-4-63	A A Stehle
D	B4	REMOVED CHECK VALVE ... D-SPEC 751323-AF A. DANIELS 4-10-64	4-10-64	



TS TR 1-1-3-5 ARE CONNECTED TO TRS-1 ALARM CHANNEL
POINTS "a" & "b" ARE LEFT HAND AND RIGHT HAND POINTERS ON CONTACT METERS RESPECTIVELY.
OFS TB 2 4 6 7 8
ND TR2 ARE ON SEPARATE PENS BUT ON A SINGLE RECORDER
ENCE DRAWINGS - CF 114407 REV D1 REVISED AS BUILT 5-5-64; 2 CF122766 REV A1 FIELD CHECKED AND REVISED AS BUILT 3-13-62
E CONNECTIONS & INSTRUMENTATION VARY WITH EACH RIMENT

LEGEND

- Y STRAINER, FLANGED
- VALVE 3-WAY
- GATE VALVE, FLANGED, MANUALLY OPERATED
- GLOBE VALVE, MANUAL REACH ROD OPERATED
- CHECK VALVE
- SOLENOID OPERATED NEEDLE VALVE
- NEEDLE VALVE, PRESSURE REGULATED
- SPRING LOADED RELIEF VALVE
- REDUCER
- FLOW MEASURING DEVICE
- BALL VALVE, FLANGED, MANUALLY OPERATED
- FLANGED CONNECTION
- INSTRUMENT ON EXPERIMENT CONTROL PANEL
- LOCALLY MOUNTED INSTRUMENT
- AA HORN AND LIGHTED PANEL (ANNUNCIATOR)
- STAINLESS STEEL FLEXIBLE ALL METAL HOSE
- ½" NOMINAL FLEXIBLE HOSE
- ELECTRICAL CONTROL
- ELECTRICAL LEADS IN TYGON TUBING
- NEEDLE VALVE

INSTRUMENTATION SYMBOLS

SYMBOL	1ST POSITION PROCESS VARIABLE	2ND & 3RD POSITION INSTRUMENT FUNCTION
A	AUDIBLE	ALARM
C		CONTROL
D		DIFFERENTIAL
E		PRIMARY ELEMENT
F	FLOW	
I		INDICATOR
M	MANUAL	
P	PRESSURE	
R		RECORDER
S		SWITCH
T	TEMPERATURE	
V		VALVE
X	POSITION	TRANSMITTER

PIPING LEGEND & MATERIAL SPECIFICATION

SYMBOL	SERVICE	MATERIAL SPEC
PC	PRIMARY COOLANT 105-145 PSIG 100-140° F	P1- 304 L CRES SCH. 10 S
P	PURGE 80 PSIG 90° F	P2- 316 CRES FLEXIBLE HOSE EQUIV TO SCH. 40
N (NOZZLE)	SAME AS PC	P3- ¼" 304 CRES TUBING
EC	EMERGENCY COOLANT 80 PSIG 90° F	
VD	VENT & DRAIN 10-15 PSIG 90-165° F	P1A-304 CRES SCH. 40S
SA	SAMPLE ACTUATING GAS 0-295 PSIG	

QTY REQ	SYM	ITEM NO	NOMENCLATURE OR DESCRIPTION	CO IDENT NO.	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	WT.	ZONE

LIST OF MATERIALS

INFORMATION CATEGORY
UNCLASSIFIED
AUTHORIZED CLASSIFIER DATE 4-3-64

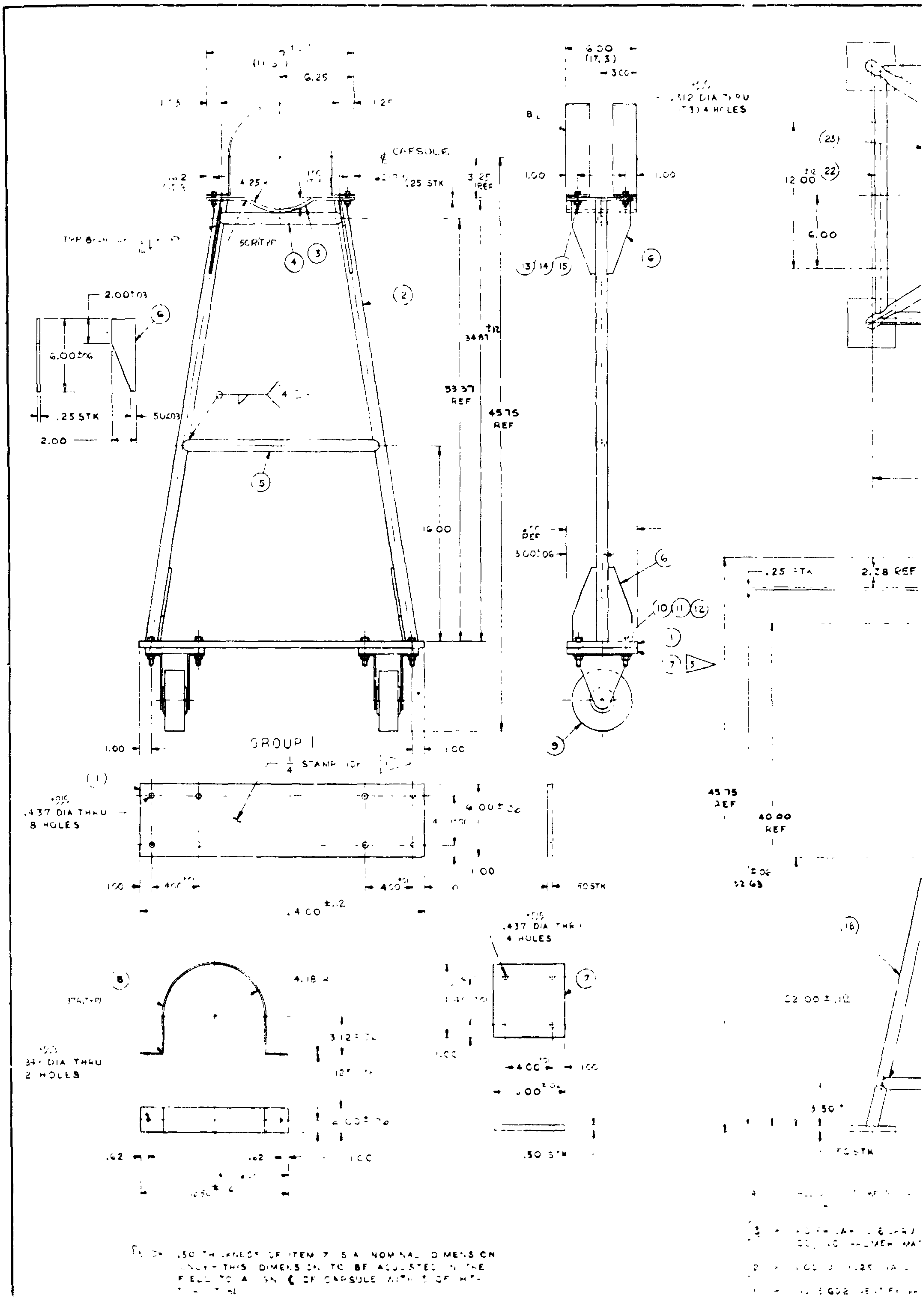
DRAWN FARKAS
CHECKED
MATERIALS
DESIGN

W. STINGHOUSE ELECTRIC CORPORATION — Astronuclear Laboratory, PITTSBURGH, PA.

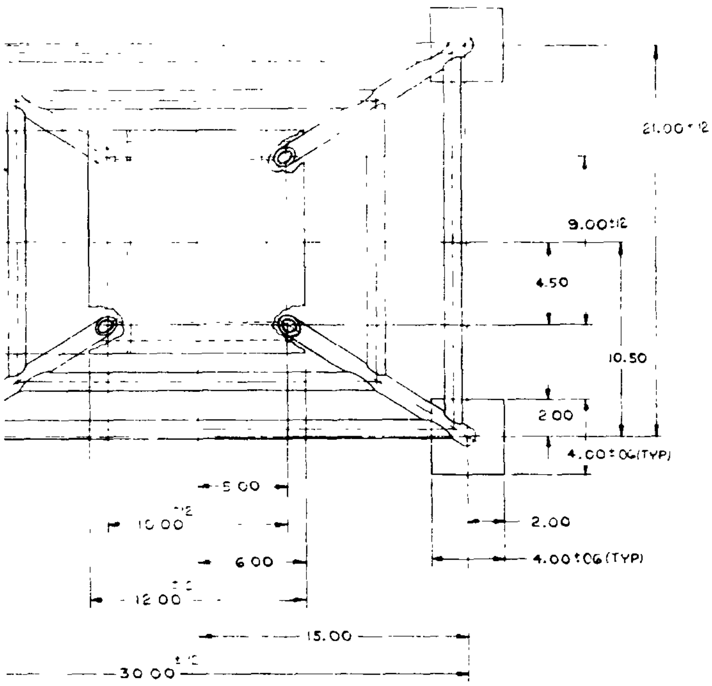
W-2 WATER COOLED INPILE CAPSULE ENGINEERING FLOW DIAGRAM

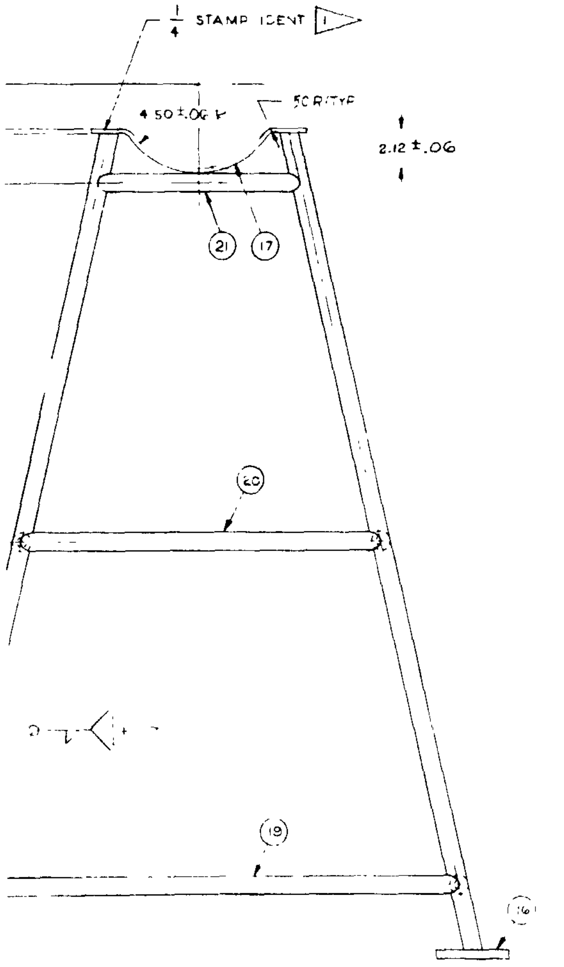
CODE IDENT NO	DWG SIZE	DWG NO.
14683	F	566F394

SCALE | WT ACT | WT CALC | SHEET 1 OF 1



6.25
CAPSULE
.25 STK
3.25 REF
4.25 R
50 R TYP
2.00±.03
6.00±.06
.25 STK
2.00
34.87
53.37 REF
45.75 REF
16.00
GROUP I
1.00
6.00
1.00
.437 DIA THRU
8 HOLES
.50 STK
6.00 (17.3)
3.00
.312 DIA THRU
4 HOLES
1.00
1.00
6.00
12.00
3.00±.06
.25 STK
2.28 REF
45.75 REF
40.00 REF
.437 DIA THRU
4 HOLES
4.18 R
.34 DIA THRU
2 HOLES
4.00
.62
.62
.50 STK
52.00 ±.12
3.50





GROUP 2

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
A	B-3	45.75 REF WAS 47.00 REF 42.63 WAS 43.88 40.00 REF WAS 41.25 REF		
	C-4	45.75 REF WAS 47.00 REF 34.87 WAS 36.12 33.37 REF WAS 34.62 REF D-751323-N D GERNHARDT 6-14-63		
B	C-5	RELOCATED ITEM 9 (CASTER) ON SUPPORT STRUCTURE 18.00 ℄ TO ℄ WAS 19.00 ADDED ITEM 6 (GUSSET) TO BASE OF SUPPORT STRUCTURE QTY REQD 8 WAS 4 D SPEC -751323-AB M. KLUCZAN 12-10-63		

G02 QTY REQD	G01	SYM	ITEM NO	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO	PART OR IDENTIFYING NO	MATERIAL	SPECIFICATION	UNIT WT.	ZONE
2		2	23	BRACE		566F395H23-	AL	6061-T6		
2		2	22	BRACE		566F395H22-	AL	6061-T6		
2		2	21	BRACE		566F395H21A	AL	6061-T6		
2		2	20	BRACE		566F395H20-	AL	6061-T6		
2		2	9	BRACE		566F395H19-	AL	6061-T6		
4		2	8	LEG		566F395H18A	AL	6061-T6		
1			17	SUPPORT		566F395H17A	AL	6061-T6		
4			16	PAD		566F395H16-	AL	6061-T6		
	4		15	.250-20UNC 2B HEX NUT			CRES	AISI 303		
	4		14	LOCKWASHER-.250 STD			CRES	AISI 303		
	4		13	.250 20UNC-2A x 1.00 LG HEX HEAD BOLT			CRES	AISI 303		
	8		12	.375-16UNC-2B HEX NUT			CRES	AISI 303		
	8		11	LOCKWASHER-.375 STD			CRES	AISI 303		
	8		10	.375-16UNC 2A x 2.00 LG HEX HEAD BOLT			CRES	AISI 303		
	2	3	9	CASTER		5-51-107				
	2		8	CLAMP		566F395H08	AL	6061-T6		
	2		7	SPACER		566F395H07-	AL	6061-T6		
	8		6	GUSSET		566F395H06-B	AL	6061-T6		
	1	2	5	BRACE		566F395H05	AL	6061-T6		
	1	2	4	SUPPORT		566F395H04A	AL	6061-T6		
	1		3	PAD		566F395H03A	AL	6061-T6		
	2	2	2	LEG		566F395H02A	AL	6061-T6		
	1		1	BLOCK		566F395H01-	AL	6061-T6		

LIST OF MATERIALS

INFORMATION CATEGORY
UNCLASSIFIED
4-3-64
AUTHORIZED CLASSIFIER DATE

F294517 PART IDENT
F294506-1 MFG INFO

751323-E

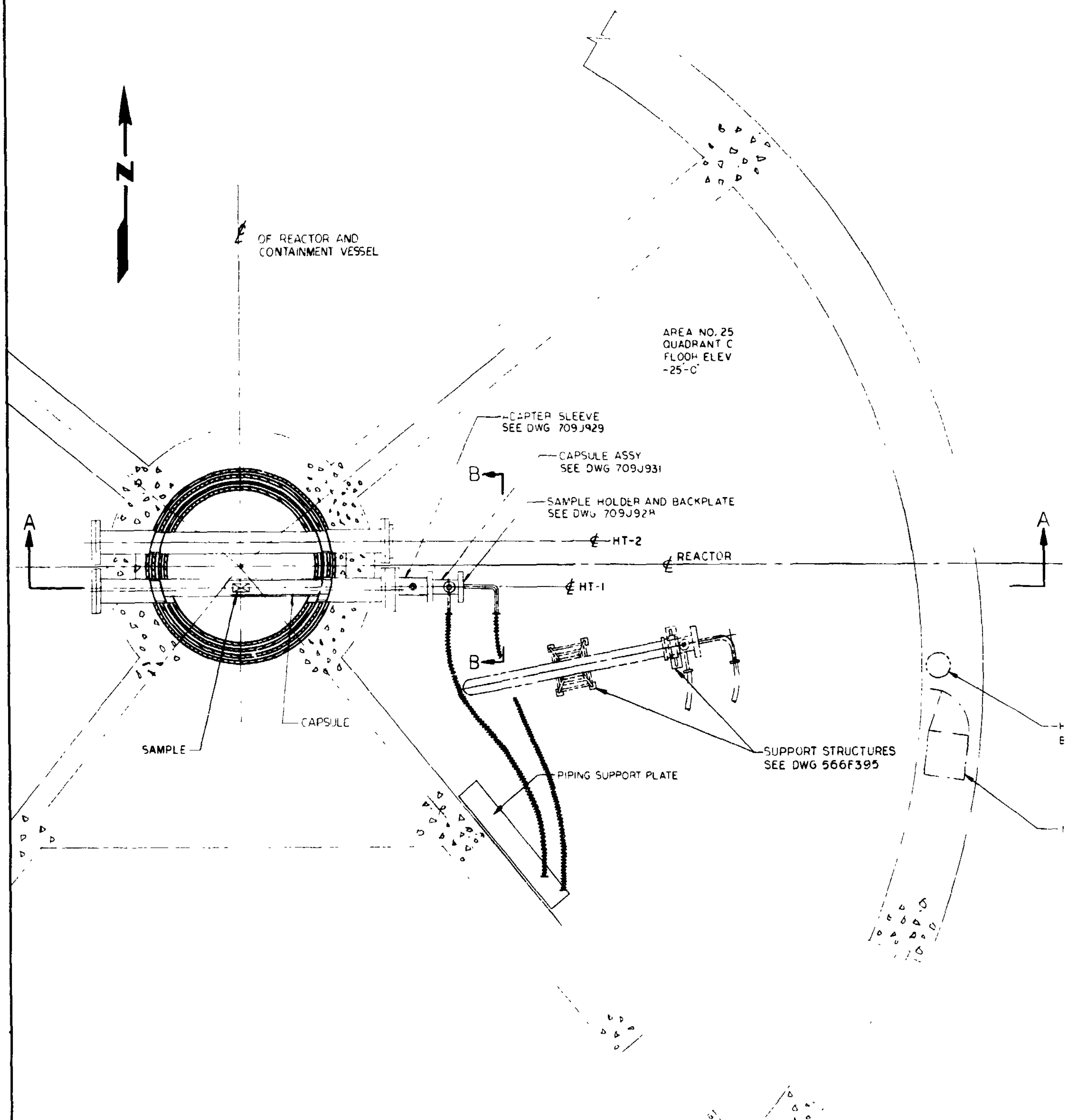
DRAWN KUBISH	DATE 5-24-63
CHECKED	6-5-63
MATERIALS	
DESIGN	6/6/63
	6-6-63

WESTINGHOUSE ELECTRIC CORPORATION
Astronuclear Laboratory
PITTSBURGH, PA.

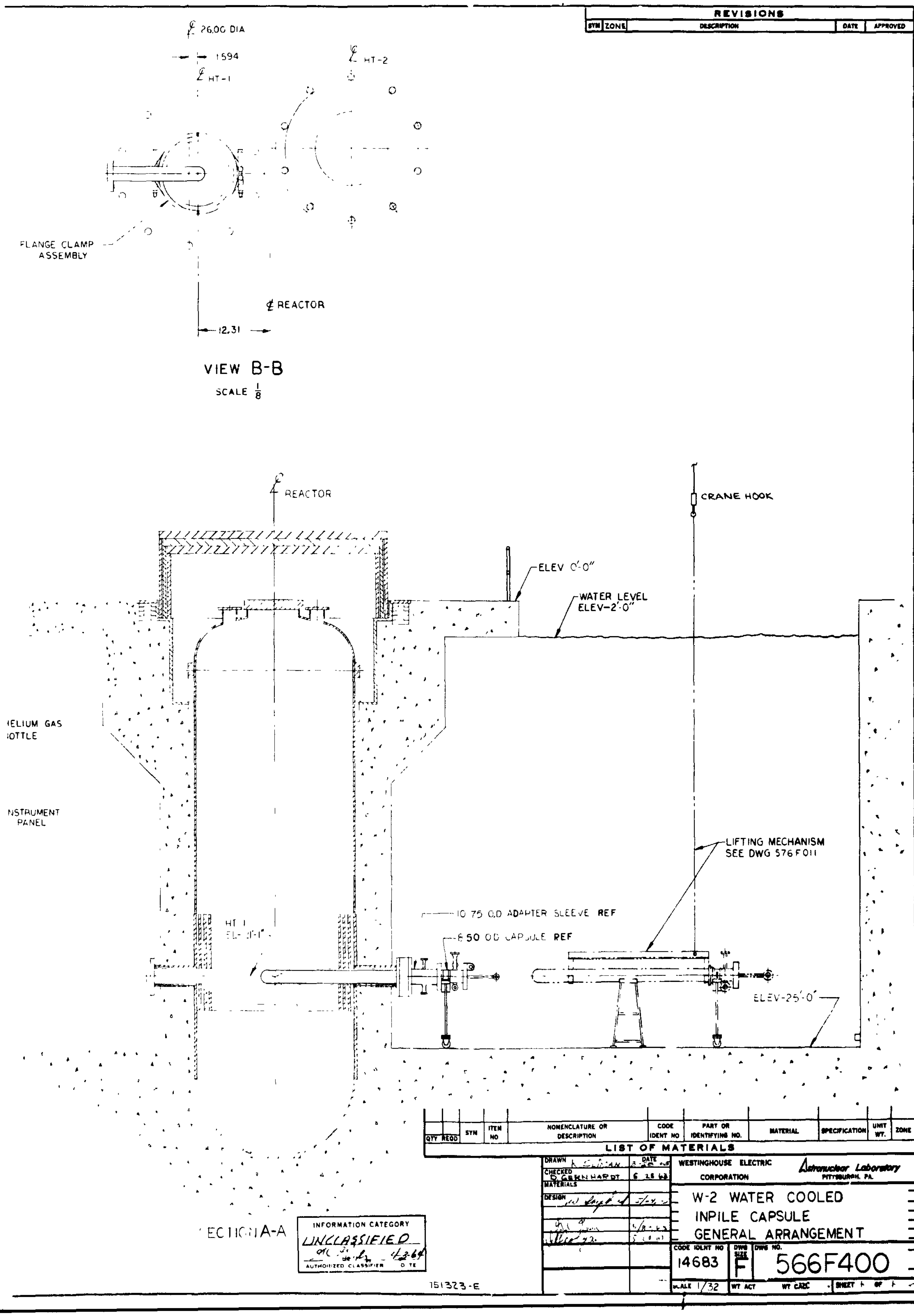
W-2 WATER COOLED INPILE CAPSULE – SUPPORT STRUCTURE DETAILS & ASSY

CODE IDENT NO	DWG SIZE	DWG NO.
14683	F	566F395

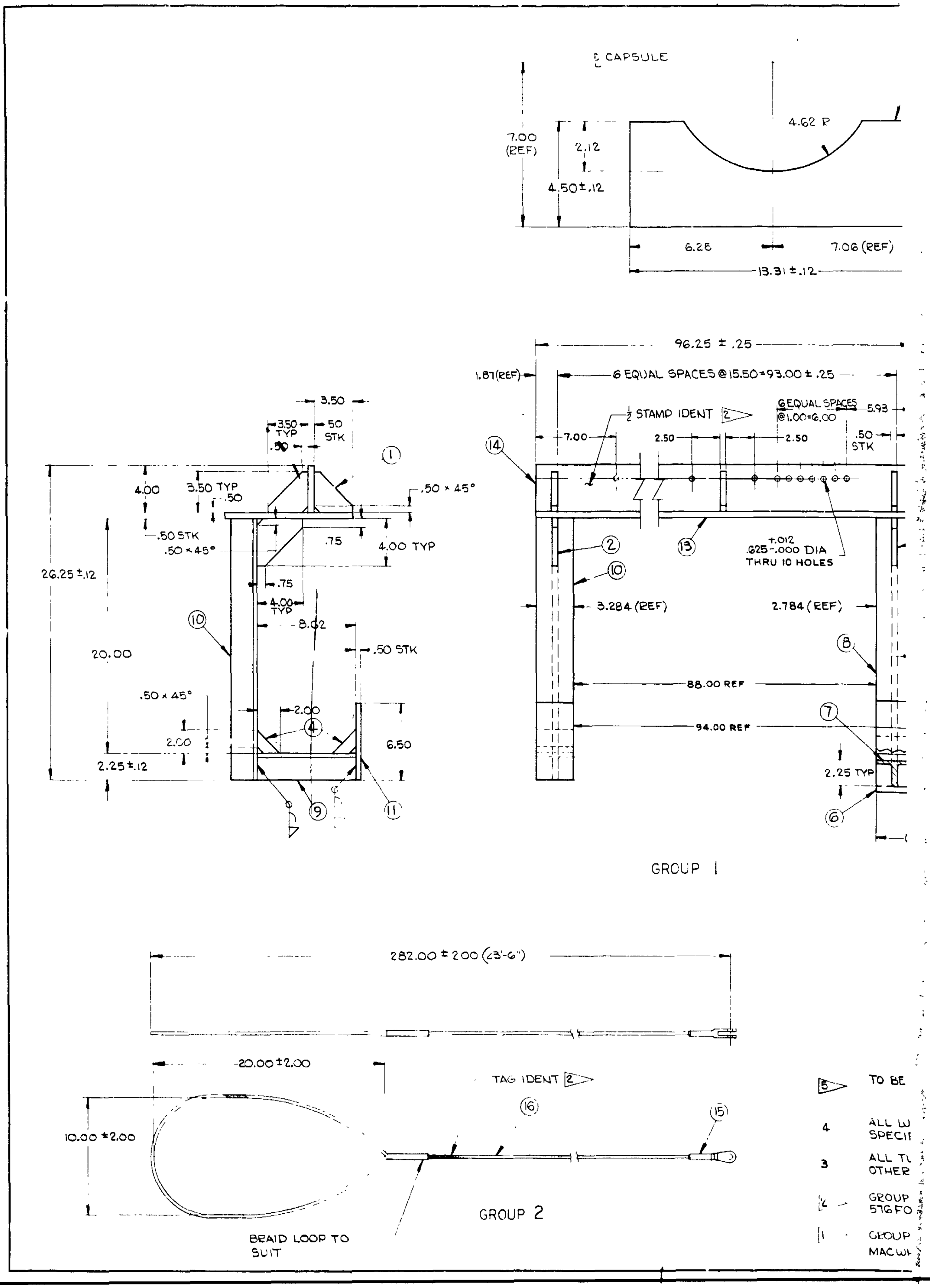
SCALE 1/4 | WT ACT | WT CALC | SHEET 1 OF 1



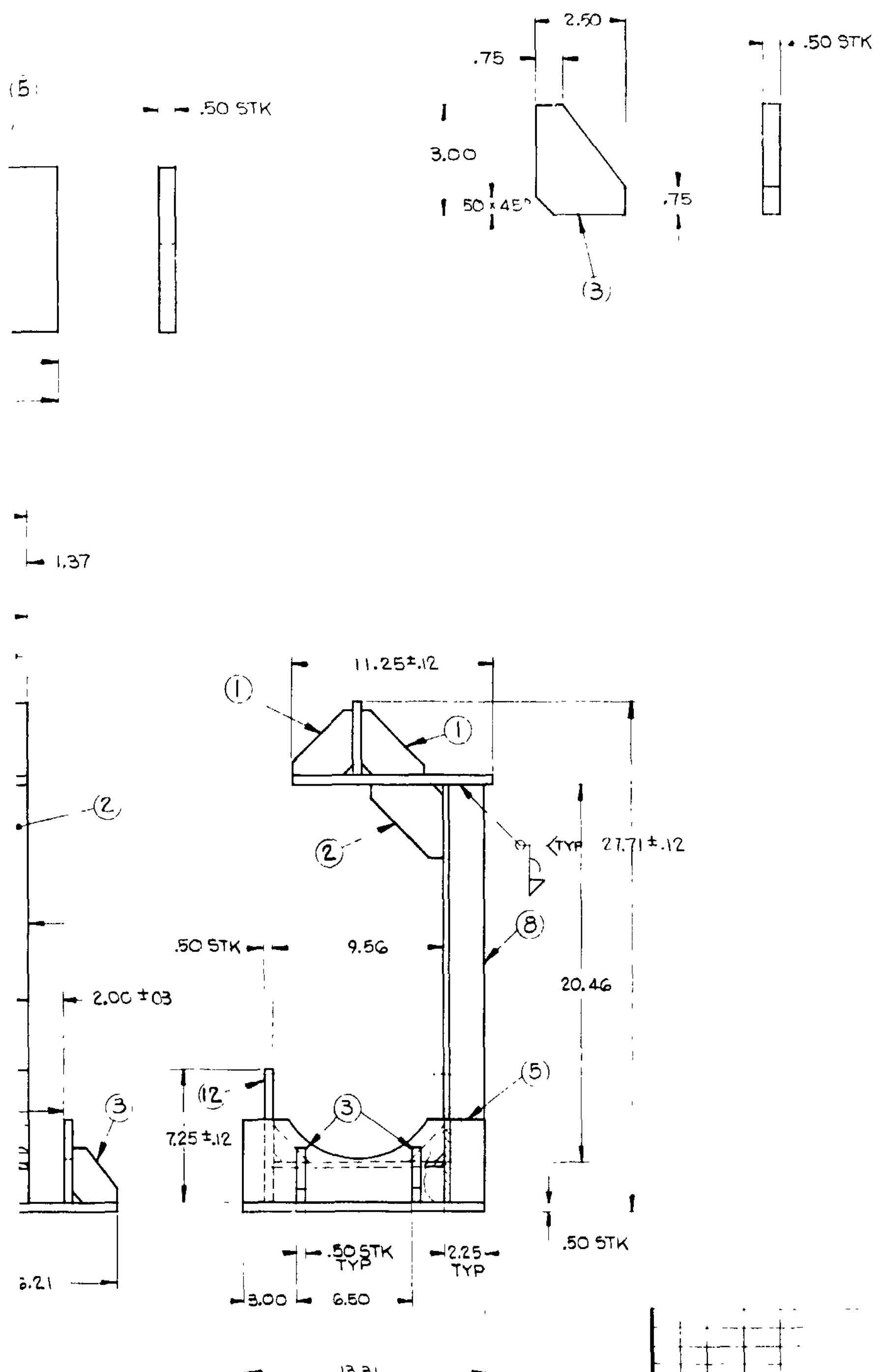
SUB-BASEMENT PLAN



REVISIONS
SYM ZONE DESCRIPTION DATE APPROVED
℄ 26.00 DIA
1594
℄ HT-1
℄ HT-2
FLANGE CLAMP ASSEMBLY
℄ REACTOR
12.31
VIEW B-B
SCALE 1/8
℄ REACTOR
CRANE HOOK
ELEV 0'-0"
WATER LEVEL ELEV-2'-0"
HELIUM GAS BOTTLE
INSTRUMENT PANEL
LIFTING MECHANISM SEE DWG 576F011
10.75 O.D ADAPTER SLEEVE REF
6.50 OD CAPSULE REF
HT 1
ELEV-25'-0"
SECTION A-A
QTY REQD SYM ITEM NO NOMENCLATURE OR DESCRIPTION CODE IDENT NO PART OR IDENTIFYING NO. MATERIAL SPECIFICATION UNIT WT. ZONE
LIST OF MATERIALS
DRAWN
CHECKED D. GERNHARDT 6-28-63
MATERIALS
DESIGN
WESTINGHOUSE ELECTRIC CORPORATION
Astronuclear Laboratory PITTSBURGH, PA.
W-2 WATER COOLED
INPILE CAPSULE
GENERAL ARRANGEMENT
CODE IDENT NO 14683
DWG SIZE F
DWG NO. 566F400
SCALE 1/32
WT ACT
WT CALC
SHEET 1 OF 1
INFORMATION CATEGORY
UNCLASSIFIED
AUTHORIZED CLASSIFIER DATE
151323-E



℄ CAPSULE
7.00 (REF)
2.12
4.50 ± .12
4.62 R
6.25
7.06 (REF)
13.31 ± .12
96.25 ± .25
1.87 (REF)
6 EQUAL SPACES @ 15.50 = 93.00 ± .25
½ STAMP IDENT 2
6 EQUAL SPACES @ 1.00 = 6.00
5.93
7.00
2.50
2.50
.50 STK
.625 +.012 -.000 DIA THRU 10 HOLES
3.284 (REF)
2.784 (REF)
88.00 REF
94.00 REF
2.25 TYP
3.50
3.50 TYP
.50 STK
.50
4.00
3.50 TYP
.50
.50 × 45°
.50 STK
.50 × 45°
.75
4.00 TYP
.75
4.00 TYP
8.62
.50 STK
26.25 ± .12
20.00
.50 × 45°
2.00
2.00
2.25 ± .12
6.50
GROUP 1
282.00 ± 2.00 (23'-6")
20.00 ± 2.00
10.00 ± 2.00
TAG IDENT 2
BRAID LOOP TO SUIT
GROUP 2
5 TO BE
4 ALL W SPECI
3 ALL T OTHER
2 GROUP 576 FO
1 GROUP MAC W



REVISIONS				
SYM	**ZONE**	**DESCRIPTION**	**DATE**	**APPROVED**
A	B4	88.00 ¢ 94.00 DIMS ADDED	4-2-64	
	C3	2.784 (REF) WAS 3.284 (REF)		
	C4	HOLES (3) AT 7.00 ¢ 2.50 DIMS ADDED	4-2-64	
	C3	$.625^{+.012}_{-.000}$ DIA THRU 10 HOLES WAS $.625^{+.012}_{-.000}$ DIA THRU 7 HOLES		
		D SPEC 751323AB DASCH 12-6-63	4-3-64	

QTY REQD GR2	QTY REQD GR1	SYM	ITEM NO	NOMENCLATURE OR DESCRIPTION	CODE IDENT NO	PART OR IDENTIFYING NO	MATERIAL	SPECIFICATION	UNIT WT.	ZONE
1			16	WIRE ROPE-.25 DIA 7x19			CRES			
1			15	OPEN SOCKET		NO SAIG3	STL	GALV		
	1		14	PLATE		576F011H14	AL	6061-T6		
	1		13	PLATE		576F011H13	AL	6061-T6		
	1		12	RETAINING PLATE		576F011H12	AL	6061-T6		
	1		11	RETAINING PLATE		576F011H11	AL	6061-T6		
	1	5	10	TEE		576F011H10	AL	6061-T6		
	1	5	9	TEE		576F011H09	AL	6061-T6		
	1	5	8	TEE		576F011H08	AL	6061-T6		
	1	5	7	TEE		576F011H07	AL	6061-T6		
	1		6	PLATE		576F011H06	AL	6061-T6		
	1		5	RETAINING PLATE		576F011H05	AL	6061-T6		
	4		4	GUSSET		576F011H04	AL	6061-T6		
	2		3	GUSSET		576F011H03	AL	6061-T6		
	2		2	GUSSET		576F011H02	AL	6061-T6		
	14		1	GUSSET		576F011H01	AL	6061-T6		

LIST OF MATERIALS

INFORMATION CATEGORY
UNCLASSIFIED
AUTHORIZED CLASSIFIER DATE

CUT FROM 5.00 ⊔ @ 5.09 LB PER FT

ELDS TO BE ¼ FILLETS UNLESS OTHERWISE
FIED

O (2) PLACE DIMENSIONS TO BE ±.06 UNLESS
WISE SPECIFIED.

1 ¢ GROUP 2 IDENTIFY PART NO'S 576F011G01-A ¢
11G02.

TO BE PURCHASED AS A COMPLETE ASSY FR
NTE CO, KENOSHA, WISC. OR APPROVED EQUAL

P294506 MFG INFO
P294517 PART IDENT

751323-E

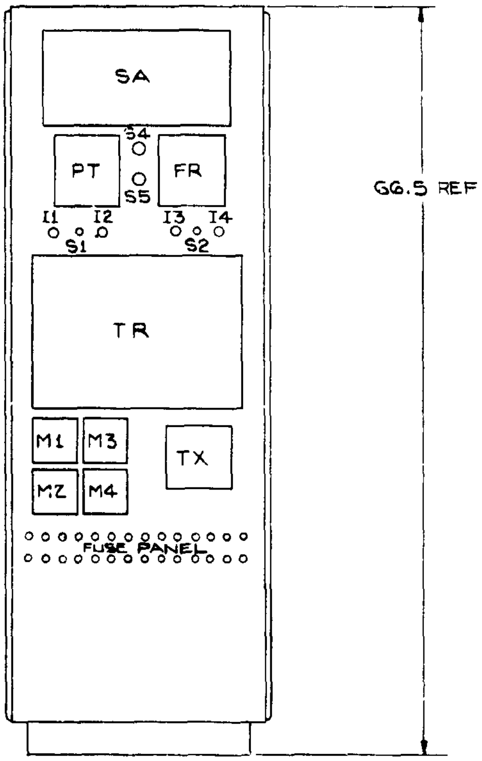
DRAWN		6-11-63
CHECKED	J. DAUGHERTY	6-11-63
MATERIALS		
DESIGN		

WESTINGHOUSE ELECTRIC CORPORATION — Astronuclear Laboratory, PITTSBURGH, PA.

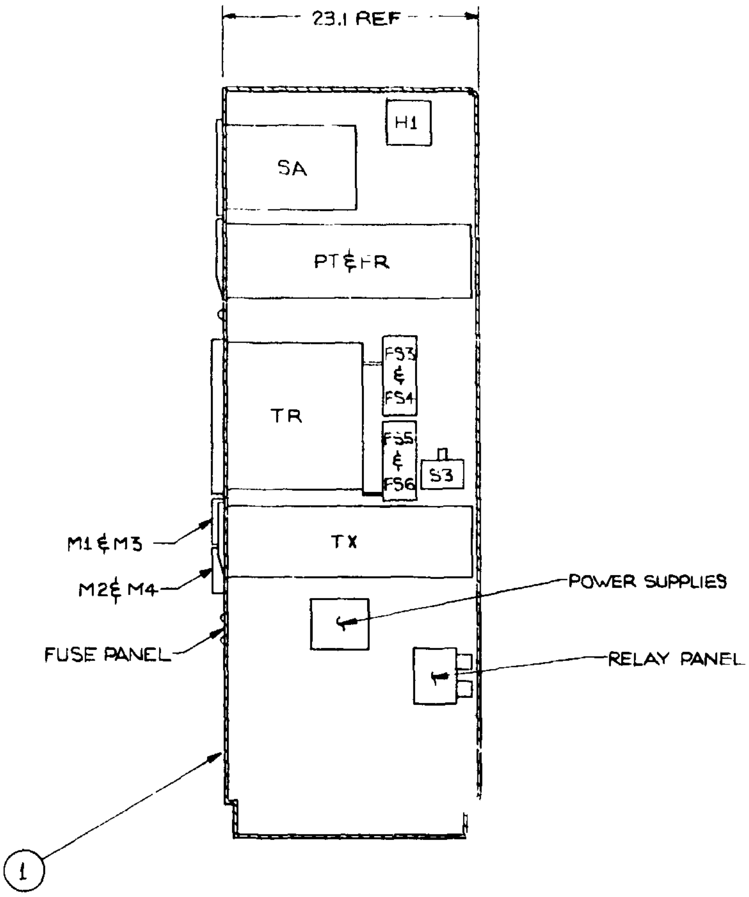
W2 WATER COOLED INPILE CAPSULE
LIFTING BAR DETAILS & ASSY

CODE IDENT NO	DWG SIZE	DWG NO
14683	F	576F011

SCALE ½ ¢ ½ | WT ACT | WT CALC | SHEET 1 OF 1



FRONT VIEW



RIGHT SIDE VIEW

H1 —

PANEL MOUNTED INSTRUMENTS

DESIGNATION*	ITEM	MODEL
FR	2-Pen Recorder	Speedomax, Type M 177090
PT	2-Pen Recorder	Speedomax, Type M 177090
M1	2-Point Contact Meter	API Model 502-L
M2	2-Point Contact Meter	API Model 502-L
M3	2-Point Contact Meter	API Model 502-L
M4	2-Point Contact Meter	API Model 502-L
P1	Power Supply	L & N, M-Line 099015
P2	Power Supply	L & N, M-Line 099015
P3	Power Supply	L & N, M-Line 099015
FS3	Monitor Switch	Minn. Honeywell 913 130-110
FS4	Monitor Switch	Minn. Honeywell 913 130-110
FS5	Monitor Switch	Minn. Honeywell 913 130-110
FS6	Monitor Switch	Minn. Honeywell 913 130-110
TX	Transmitter	L & N, M-Line 177093
TR	Multipoint Recorder	Daystrom Model 6704
SA	Annunciator	Scam, S-Line ACS-9
S1	Switch, By-Pass Test	DPDT Toggle-Spring Return Center Off
S2	Switch, By-Pass Test	DPDT Toggle-Spring Return Center Off
S3	Circuit Breaker	15 amp. General Electric
S4	Switch, Lamp Test	DPST
S5	Switch, Acknowledge	DPST
H1	Horn	120 VAC
AM	Module Alarm	Build by Plum Brook Reactor Facility
R10	Relay	120 VAC Potter Brumfield KR 5295
R12	Relay	120 VAC Potter Brumfield KR 5295
R13	Relay	120 VAC Potter Brumfield KR 5295
R14	Relay	120 VAC Potter Brumfield KR 5295
R11	Relay-Amplifier	API Model 903
I1	Lamp	120 VAC Dialco 95408-935
I2	Lamp	120 VAC Dialco 95408-935
I3	Lamp	120 VAC Dialco 95408-935
I4	Lamp	120 VAC Dialco 95408-935

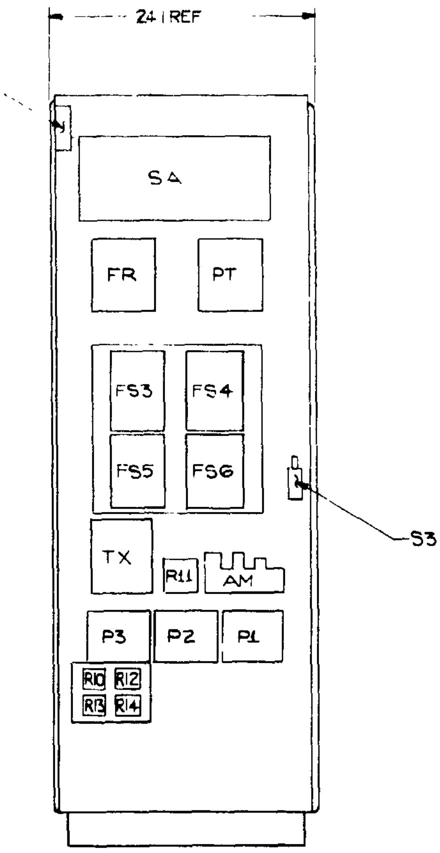
*3 DESIGNATIONS FOR THIS PRINT TAKE

2 FOR FLOW DIAGRAM SEE DWG 5
FOR WIRING DIAGRAM SEE Ⓦ DWG
FOR ALARM & SCRAM SCHEMATIC SE
FOR PANEL LOCATION SEE DWG

1 > BUD CO, CLEVELAND, OHIO OR EQ

NOTE

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED
B		REDRAWN AND CHANGED TO SUIT AS BUILT SPECS. 751323-AK R.NOWICKI 7-1-64	7-1-64 7-7-64 7-7-64	H.O. Blinn A A



REAR VIEW

QTY REQD	SYM	ITEM NO.	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	UNIT WT.	ZONE
1	1	1	RELAY RACK, PRESTIGE MODEL	CR-2280	STL	GRAY FINISH		

LIST OF MATERIALS

...N FROM W DWG NO. 577F042
...6F394 REV F.
NO. 577F042.
E W DWG NO. 577F041.
566F400.
...JAL.

INFORMATION CATEGORY
Unclassified
7/7/64

NE 1980 M

DFTM.	TUCKER	5-29-63
CHECKER	J.W DORAN	6-6-63
DESIGN	W. SHEPHERD	6-7-63
ANALYSIS		
MATL.		
RELIAB. & Q. A.		
MFG.		
DFTM SUPV.		
	G.C GESLER	6-7-63

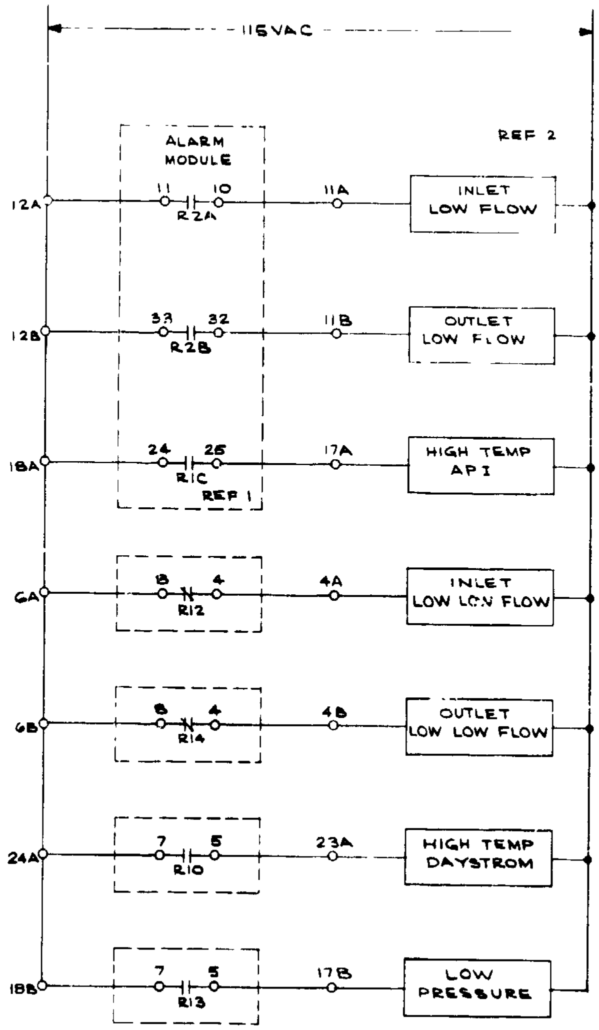
WESTINGHOUSE ELECTRIC CORPORATION
Astronuclear Laboratory
PITTSBURGH, PA

W2 WATER COOLED INPILE CAPSULE PANEL ARRANGEMENT

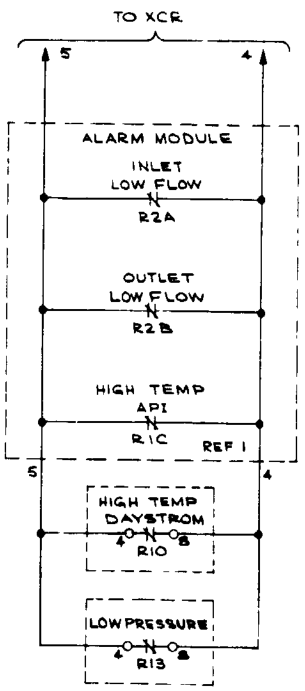
CODE IDENT NO.	DWG SIZE	DWG NO.
14683	D	386D718

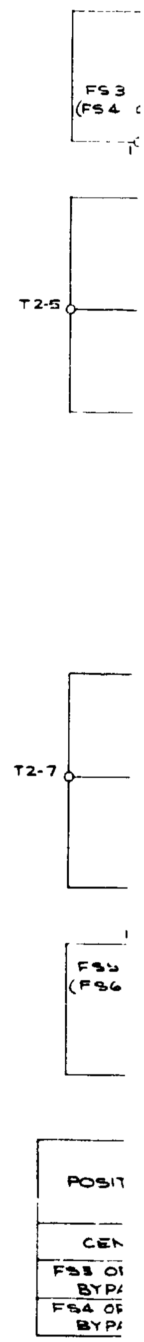
386D718

LOCAL ALARM CIRCUIT
(SCAM ANNUNCIATOR UNIT)

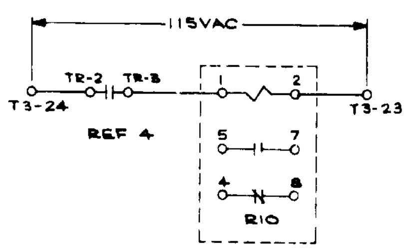


SUMMATION ALARM

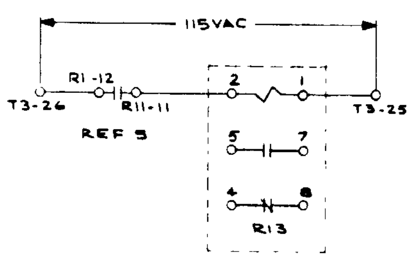




DAYSTROM RECORDER
RELAY DETAIL



API LOW PRESSURE
RELAY DETAIL



DESIGNATIONS

AM	ALARM MODULE BUILT BY PLUM BROOK REACTOR FACILITY
API	ASSEMBLY PRODUCTS, INC MODEL 903
FS3	MONITOR SWITCH, MINNEAPOLIS HONEYWELL 913-130-110
FS4	MONITOR SWITCH, MINNEAPOLIS HONEYWELL 913-130-110
FS5	MONITOR SWITCH, MINNEAPOLIS HONEYWELL 913-130-110
FS6	MONITOR SWITCH, MINNEAPOLIS HONEYWELL 913-130-110
I1	INDICATOR LIGHT DIALCO 95408-935
I2	INDICATOR LIGHT DIALCO 95408-935
I3	INDICATOR LIGHT DIALCO 95408-935
I4	INDICATOR LIGHT DIALOC 95408-935
R10	RELAY DPDT 115 VAC POTTER & BRUMFIELD KR 5295
R11	RELAY ASSEMBLY PRODUCTS, INC MODEL 903
R12	RELAY DPDT 115 VAC POTTER & BRUMFIELD KR 5295
R13	RELAY DPDT 115 VAC POTTER & BRUMFIELD KR 5295
R14	RELAY DPDT 115 VAC POTTER & BRUMFIELD KR 5295
TR	TEMPERATURE RECORDER DAYSTROM MULTIPOINT MODEL 6704
S1	TEST SWITCH DPDT SPRING RETURN TO CENTER OFF
S2	TEST SWITCH DPDT SPRING RETURN TO CENTER OFF
T2	TERMINAL BOARD NO 2
T3	TERMINAL BOARD NO 3 - FUSE PANEL
XCR	EXPERIMENTAL CONTROL ROOM

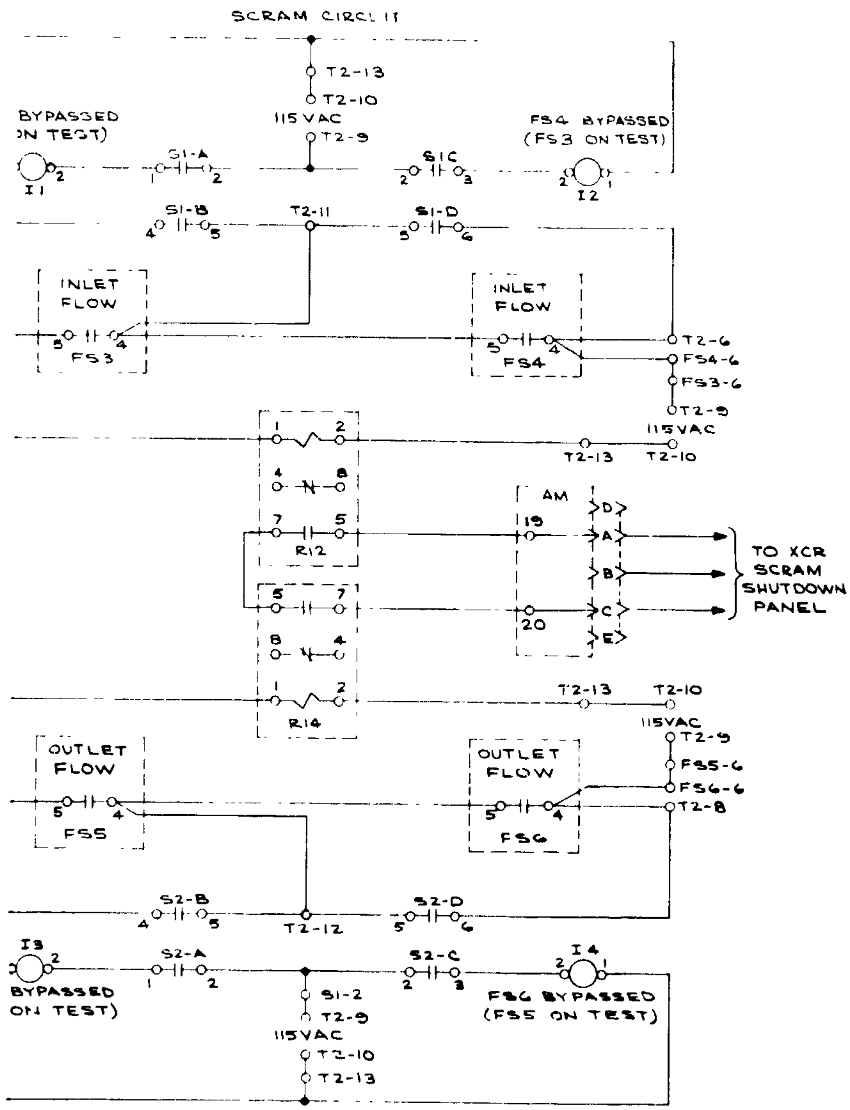
REFE

1	OPERATION AND MAINT WESTINGHOUSE EXPERIM
2	SCRAM INSTRUCTIONS A DRAWING NO ACS-9A-
3	MINNEAPOLIS HONEYW 334- ISSUE 2 FIGURE 5A
4	DAYSTROM MANUAL FO
5	ASSEMBLY PRODUCTS, IN

2. COPIED FROM WANL SK109. REFERENCE DESIGNATIONS ARE NOT IN ACCORDANCE WITH MIL-STD-16 & SYMBOLS ARE NOT IN ACCORDANCE WITH MIL-STD-15.

1. RELAYS SHOWN IN DE-ENERGIZED POSITION.

NOTES:



S1 AND S2

IONS	SWITCH CONTACTS A OPEN	A CLOSED	B OPEN	B CLOSED	C OPEN	C CLOSED	D OPEN	D CLOSED
TER	X		X		X		X	
; FS5 SSED		X		X	X		X	
. FS6 SSED	X		X			X		X

ENCES

NANCE MANUAL FOR TRIP CIRCUIT
ENT NO. 43-05

ND OPERATIONS MANUAL SC AC
REV. B

NUAL

MODEL ... MULTI-STATION RECORDER

DRA...

LIST OF MATERIALS

QTY REQD	SYM	ITEM NO.	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO.	MATERIAL	SPECIFICATION	UNIT WT	ZONE

REVISIONS

SYM	ZONE	DESCRIPTION	DATE	APPROVED

DRWN F.C. BONIDIE 7-?-64
CHECKER M. DeFILIPPE 7-3-64
DESIGN E. LLEWELLYN 7-7-64
ANALYSIS
MATL
RELIAB & Q A
MFG
DPTM SUPV

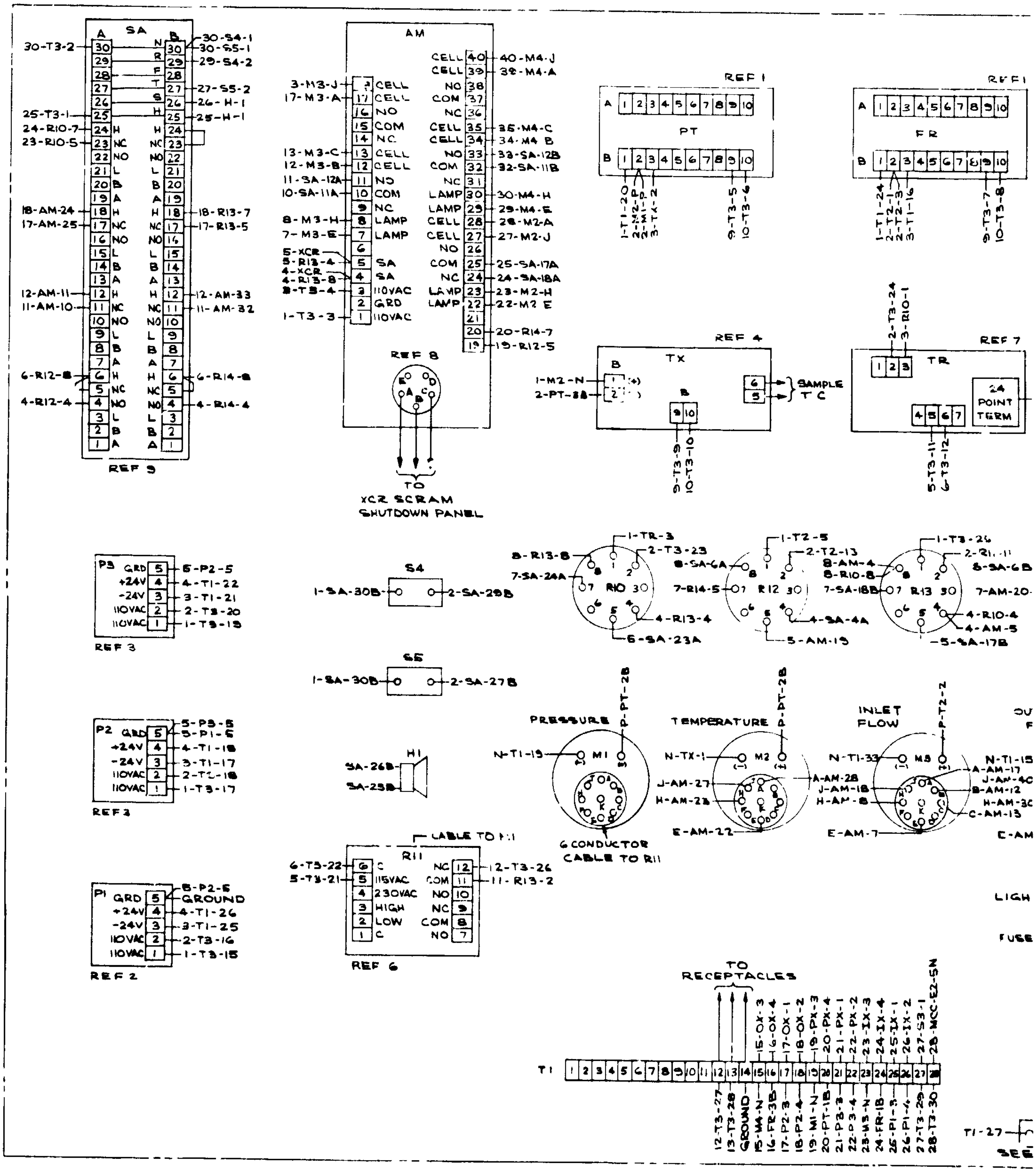
WESTINGHOUSE ELECTRIC CORPORATION
Astronuclear Laboratory
PITTSBURGH, PA.

SCHEMATIC DIAGRAM - ALARM AND SCRAM SYSTEM N2 WATER COOLED INPILE CAPSULE

CODE IDENT NO 14683 | DWG SIZE F | DWG NO 577F041

INFORMATION CATEGORY

7-1323 AK



4 COPIED FROM WANL SK108

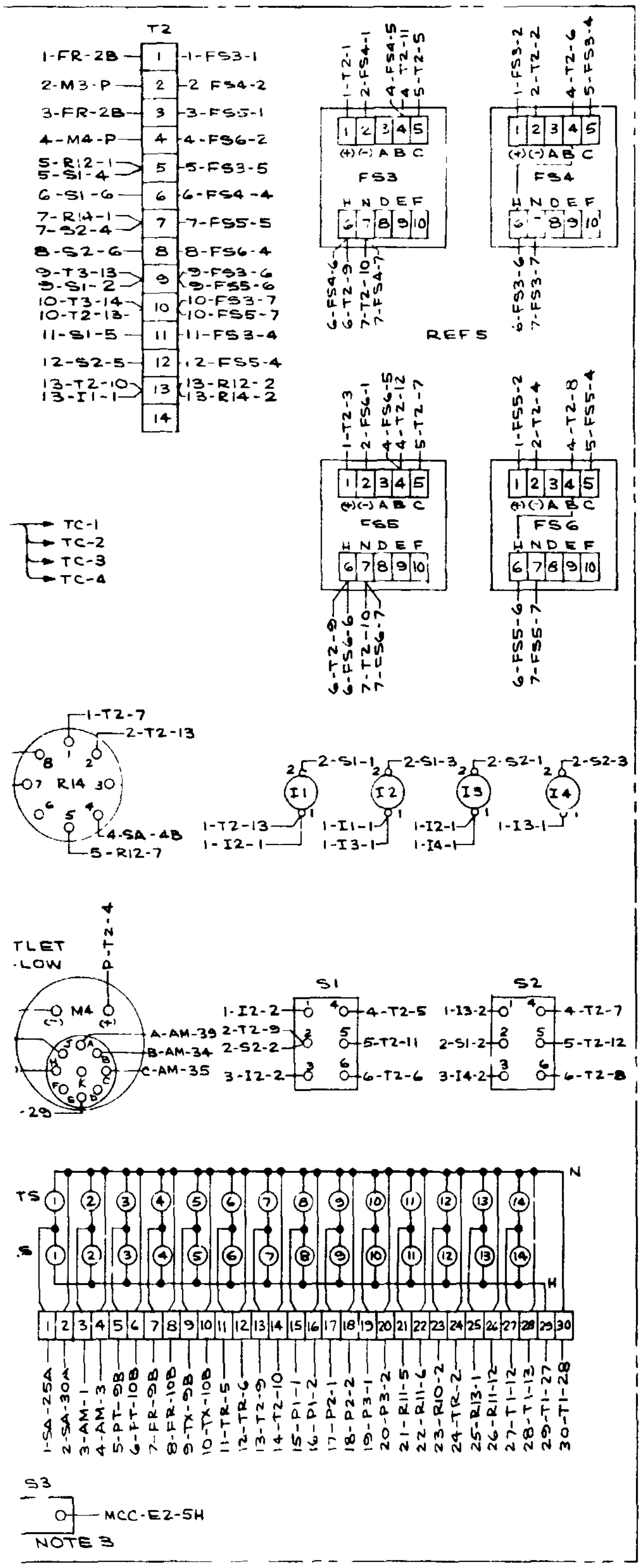
3 LINE SWITCH IS A 15 AMP CIRCUIT BREAKER

2 CABLE FROM R11 TO M1 IS 6 CONDUCTOR INTERNALLY WIRED TO R11 & CONNECTED TO M1 BY A 9 PIN CONNECTOR

1 THE 24 POINT TERMINAL BOARD CAN BE CONVERTED TO THE NUMBER OF POINTS DESIRED DEPENDING ON EXPERIMENT REQUIREMENTS

NOTES

REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED



MARKING SYSTEM

AM	ALARM MODULE BUILD BY PLUM BROOK REACTOR FACILITY
FS3	MONITOR SWITCH, MINNEAPOLIS HONEYWELL 913-130-110
FS4	MONITOR SWITCH, MINNEAPOLIS HONEYWELL 913-130-110
FS5	MONITOR SWITCH, MINNEAPOLIS HONEYWELL 913-130-110
FS6	MONITOR SWITCH, MINNEAPOLIS HONEYWELL 913-130-110
FR	FLOW RECORDER LEEDS & NORTHRUP M LINE 177090
H1	HORN
I1	INDICATOR LIGHT - DIALCO 95408-935
I2	INDICATOR LIGHT - DIALCO 95408-935
I3	INDICATOR LIGHT - DIALCO 95408-935
I4	INDICATOR LIGHT DIALCO 95408-935
IX	INLET FLOW TRANSMITTER LEETS & NORTHRUP 177098
OX	OUTLET FLOW TRANSMITTER LEEDS & NORTHRUP 177098
PX	PRESSURE TRANSMITTER LEEDS & NORTHRUP 177097
PT	PRESSURE/TEMPERATURE RECORDER LEEDS & NORTHRUP M LINE 177090
P1	POWER SUPPLY NO 1 LEEDS & NORTHRUP 099015
P2	POWER SUPPLY NO. 2 LEEDS & NORTHRUP 099015
P3	POWER SUPPLY NO 3 LEEDS & NORTHRUP 099015
M1	METER (PRESSURE) ASSEMBLY PRODUCTS, INC. 502-L0-5 MA
M2	METER (TEMPERATURE) ASSEMBLY PRODUCTS, INC. 502-L0-5 MA
M3	METER (INLET FOLW) ASSEMBLY PRODUCTS, INC. 502-L0-5 MA.
M4	METER (OUTLET FLOW) ASSEMBLY PRODUCTS, INC. 502-L0-5 MA.
R10	RELAY NO. 10 115 VAC DPDT POTTER & BRUMFIELD KR 5295
R11	RELAY NO 11 ASSEMBLY PRODUCTS, INC. 903
R12	RELAY NO 12 115 VAC DPDT POTTER & BRUMFIELD KR 5295
R13	RELAY NO 13 115 VAC DPDT POTTER & BRUMFIELD KR 5295
R14	RELAY NO. 14 115 VAC DPDT POTTER & BRUMFIELD KR 5295
SA	SCAM ANNUNCIATOR UNIT
S1	BYPASS-TEST SWITCH DPDT SPRING RETURN TO CENTER OFF
S2	BYPASS-TEST SWITCH DPDT SPRING RETURN TO CENTER OFF
S3	LINE SWITCH 15 AMP TRIP
S4	ACKNOWLEDGE SWITCH
S5	TEST SWITCH
T1	TERMINAL BOARD NO 1
T2	TERMINAL BOARD NO 2
T3	TERMINAL BOARD NO. 3
TX	TEMPERATURE TRANSMITTER LEEDS & NORTHRUM 177093
TR	TEMPERATURE RECORDER DAYSTROM 6704

EXTERNAL CONDITIONS

XCR	EXPERIMENT CONTROL ROOM
MCC E2 5	MOTOR CONTROL CENTER E2 BREAKER NO. 5
TC	THERMOCOUPLE

		FLOW DIAGRAM 566F394 DESIGNATION
PRESSURE METER	M1 UPPER SETPOINT LOWER SETPOINT (NOT USED)	PS 1 b
TEMPERATURE METER	M2 LOWER SETPOINT UPPER SETPOINT (NOT USED)	TS 2 a
INLET FLOW METER	M3 UPPER SETPOINT LOWER SETPOINT (NOT USED)	FS 1 b
OUTLET FLOW METER	M4 UPPER SETPOINT LOWER SETPOINT (NOT USED)	FS 2 b

REFERENCES

1 a. L & N MANUAL 177090 ISSUE 4 FIGURE 35
  b. L & N DRAWING NO. J-M-62-200-20 REV. 2

2. a. L & N MANUAL 177097 ISSUE 2 FIGURE 9
  b L & N DRAWING NO. B-D-2291-16A
  c. L & N DRAWING NO. J-D-2291-16

3 a L & N MANUAL 177097 ISSUE 2 FIGURE 9
  b L & N DRAWING NO B-D-2291-17A
  c L & N DRAWING NO. J-D-2291-17

4. a L & N MANUAL 177093 ISSUE 5 FIGURE 15
  b L & N DRAWING NO A-D-1901-2 REV. 4
  c L & N DRAWING NO 101076 ST 2 REV. 20

5 MINNEAPOLIS HONEYWELL MANUAL 334-0 ISSUE 2 FIGURE 5A

6 ASSEMBLY PRODUCTS, INC DRAWING NO 2783-1

7 DAYSTROM MANUAL FOR MODEL 6704 MULTIPLE-STATION RECORDER

8. OPERATION AND MAINTENANCE MANUAL FOR TRIP CIRCUIT WESTINGHOUSE EXPERIMENT NO 63-05

9 SCAM INSTRUCTIONS AND OPERATIONS MANUAL SC-AC DRAWING ACS-9A-F REV. 8

QTY REQD	SYM	ITEM NO	NOMENCLATURE OR DESCRIPTION	PART OR IDENTIFYING NO	MATERIAL	SPECIFICATION	UNIT WT.	ZONE

LIST OF MATERIALS

DFTM. F C Bonidie	7-3-64	WESTINGHOUSE ELECTRIC CORPORATION — Astronuclear Laboratory PITTSBURGH, PA.
CHECKER M De Filippo	7-3-64	
DESIGN E. Llewellyn	7-7-64	WIRING DIAGRAM-
ANALYSIS		
MATL		
RELIAB & Q A		W-2 WATER COOLED INPLE CAPSULE
MFG		
DFTG SUPV	7-6-64	CODE IDENT NO. 14683 — DWG SIZE F — DWG NO 577F042

INFORMATION CATEGORY
Unclassified
7/7/64

751323-AK

APPENDIX A

DESIGN DATA FOR NORMAL OPERATION

DESIGN DATA FOR NORMAL OPERATION

Capsule	75 gpm
HT-1 Inlet Temperature	135°F
Coolant Exit Temperature	153.6°F
Design Metal Temperature	300°F
Maximum Operating Capsule Wall Temperature	188.2°F
Maximum Capsule Differential Pressure	138 psi
Maximum Operating Pressure	160 psia
Hydrostatic Test Pressure (External Pressure)	207 psig
Peak Gamma Heating Rate at 60 Mw Reactor Power	8 watts/g

APPENDIX B

EQUIPMENT-PROCEDURES

B.1 INSPECTION AND TEST PROCEDURES

This specification covers the requirements for fabrication, factory tests and installation tests of an in-pile water-cooled capsule assembly, consisting of capsule, sample holder, adapter sleeve, instrumentation and miscellaneous other items as shown on WANL Drawings 386D715, 709J928, 709J929, 709J930, 709J931, 566F38 , 566F387, and 566F391.

Design Conditions - The capsule is designed for the following conditions:

External Operating Pressure, 160 psig

Maximum Operating Temperature, 300°F

Certification of Materials - The vendor shall furnish certificates for approval on all materials used in accordance with the applicable ASTM specifications.

Procedures - The following describes the type of inspection and test procedures to be used for the custom-built equipment.

B.1.1 Dye-Penetrant Test

Each weld joint including tack welds and attachment welds shall be inspected using a commercial penetrant approved by the Contracting Officer at the intervals noted below. The procedure for using the penetrant shall conform with ASTM E 165 except that procedures A-1 and B-1 shall not be employed. All penetrant indications prove the presence of defects shall be cause for rejection or repair as specified hereinafter.

(a) All single welded joints shall receive liquid penetrant inspection on the outside surface of the root pass and the outside of the finished weld surface.

(b) All double welded joints shall receive liquid penetrant inspection on the prepared "back-groove" surface and on both finished weld surfaces upon completion of the weld.

(c) All weld beads where visual inspection indicates possible cracking, incomplete fusion or overlap shall be penetrant inspected and corrective action taken if necessary before welding is continued.

(d) The dye-penetrant tests will be inspected and approved by the Contracting Officer.

B.1.2 Radiographic Test

Radiographic inspection shall conform with UW-51 of Section VIII of the ASME Code except as modified herein. The quality of the radiography shall meet the requirements of ASTM Specification E142 for quality level 2-1T. Radiography inspection shall be made on all pressure or containment welds and all procedure and welders qualification test welds.

The inspection area shall include the weld and the base metal 1 inch on either side of the weld. Insofar as possible, the penetrameter shall be placed on the source side of the joint; and radiographs shall be made through only one wall of the plate or pipe being examined. Where it is necessary to make the radiograph through both walls of the pipe or plate, the penetrameter thickness shall be based on a single wall thickness; only the image of the portion of the weld nearest the film shall be considered; images shall not be superimposed. The adequacy of techniques which deviate from the above must be demonstrated to the complete satisfaction of the Contracting Officer.

Criteria for Rejection - Any weld which shows evidence of the following defects shall be rejected:

a. Any type of crack or zone of incomplete fusion or penetration.

b. Any combination of metallic or metal oxide inclusions or porosity in excess of that shown on the applicable "Porosity Chart", Appendix IV, Section VIII of the ASME Code. (For material thicknesses less than 1/4 inch, the maximum size of any such individual imperfection shall not exceed 10 per cent of the base metal thickness.)

Repairs - Weld repairs shall be made only with the knowledge and prior approval of the Contracting Officer. The defect shall be completely exposed and removed by shipping, grinding, machining, or other mechanical means. Before welding, the defect area shall be thoroughly examined visually and with the aid of penetrants. Any additional defects exposed shall be removed. The repair weld shall be made by the same procedure as the original weld and shall meet all requirements of this specification, including penetrant inspection and radiographic inspection where applicable.

Inspection - The radiographs will be inspected and approved by the Contracting Officer.

B.1.3 Hydrostatic Test

The vendor shall perform the following tests on capsule components and on the completed capsule assembly and shall submit his test procedure for the Contracting Officer's approval prior to testing. All tests will be witnessed and approved by the Contracting Officer.

Test Pressure - An internal hydrostatic test of 240 psig shall be applied to the in-pile capsule and the HT-1 Adapter Assembly.

Test Procedure - The following shall apply to hydrostatic tests:

a. Hydrostatic tests shall be made with unused, distilled or demineralized water containing not more than 10 ppm of solids.

b. Pressure shall be applied in increments of not more than 25 psi; and after each increment of pressure increase, a minimum of 10 minutes must be allowed to examine welds and permit the assemblies to come to equilibrium. When pressure has reached the required test pressure, it shall be held for 24 hours without any drop in pressure on the test gage.

c. If any leaks are detected, the pressure must be relieved and the leak repaired. Vendor must inform the Contracting Officer of proposed method of repairing the leak and obtain approval of same before proceeding with the work. When pressure has reached the required test pressure, all welds shall be carefully examined, x-rayed same as new welds; and the pressure shall be held for an additional 22 hours during which time an hourly record of the pressure gage readings shall be maintained.

d. Every precaution must be taken during testing to insure that the interior of the assemblies remain absolutely clean.

e. After hydrostatic tests, the assemblies shall be rinsed with unused, distilled or demineralized water containing not more than 10 ppm solids. After rinsing, the assemblies shall be drained and dried with oil free air.

B.1.4 Connection Box Test

All watertight connection boxes shall be pressure tested with nitrogen to 20 psig to insure watertight integrity.

B.1.5 Radiation Effects Testing of Brazed Joint

An instrumented transition piece of 304L stainless steel joined to 3003 aluminum, and contained within a capsule (Figure B.1), was tested in the Ground Test Reactor in May and June, 1963, to determine the effects of neutron and gamma irradiation of the brazed joint and test data has been published.*

The test consisted of pressurizing the sample with gaseous N_2 to 150 psig and at approximately 8-hour intervals, evacuating the gas inside the sample joint and then externally pressurizing the joint to 150 psig. Cycling

*Reference B.1, page 254-256.

between internal and external pressurization was done to simulate the water-cooled capsule conditions encountered during sample changing operations. The test temperature was ~120°F and the duration was ~300 hours.

Figure B.2 is a sketch of the test fixture. The test joint differs from the W-2 capsule joint in size, wall thickness, and strength (alloy). Although radiation damage induced in the different aluminum alloys cannot be factored out, existing nvt data on the two alloys will be correlated to determine radiation induced changes in a 6061-T6 joint from measured changes in the 3003 joint.

At GTR, the test joint was exposed to a fast neutron flux of 6×10^{8} nv (E >0.1 Mev), and a total integrated fast neutron flux of 6.4×10^{11} nvt, and integrated thermal neutron flux of 2.8×10^{15} nvt. The W-2 capsule joint, based on extrapolated preliminary measurementa at a 19 kw reactor power level, should be exposed to a fast neturon flux of about 7×10^{7} n/cm^2-sec. This corresponds to an integrated fast neutron flux of 3×10^{14} n/cm^2. Thus, approximately 138 hours of irradiation time in GTR provides an equivalent exposure to the PBR W-2 capsule. The calculated gamma heating rate in the GTR test capsule was 645 BTU/hr and in the sample joint 241 BTU/hr, based on a gamma heat rate of 5.2×10^{-2} W/gm.

B.2 FABRICATION

The following specifications apply to all materials used for fabrication of the in-pile assembly:

a. Aluminum alloy tubing shall be drawn seamless as per ASTM B 210 alloy 6061.

b. Aluminum alloy sheet and plate shall be in accordance with ASTM B 209 alloy 6061.

c. Aluminum alloy bars, rods, and wire shall be in accordance with ASTM B 211 alloy 6061.

d. All aluminum components shall be of the T-6 temper throughout.

e. Aluminum Unitrace shall be 6063-T5 Alcoa Unitrace or equal.

f. Stainless steel tubing shall be seamless or welded in accordance with A 269.

g. Stainless steel plate, sheet and strips shall be in accordance with ASTM A 167 TP 304.

h. All stainless steel components shall be treated after completion of fabrication and surface finishing. The treatment shall consist of immersion in an 18-22 per cent nitric acid and 1-1/2 - 2-1/2 per cent sodium dichromate solution at 120-140°F for 30 minutes and rinsed in water and then thoroughly dried.

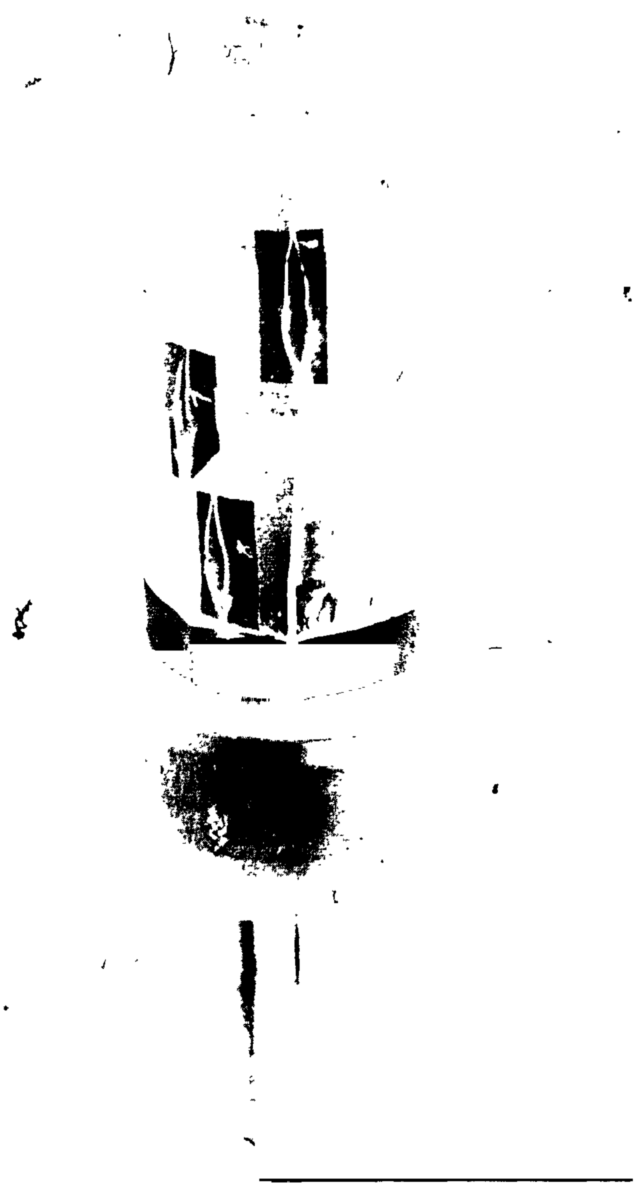


Figure B.1 - Instrumented Aluminum-Stainless Steel Transition Piece

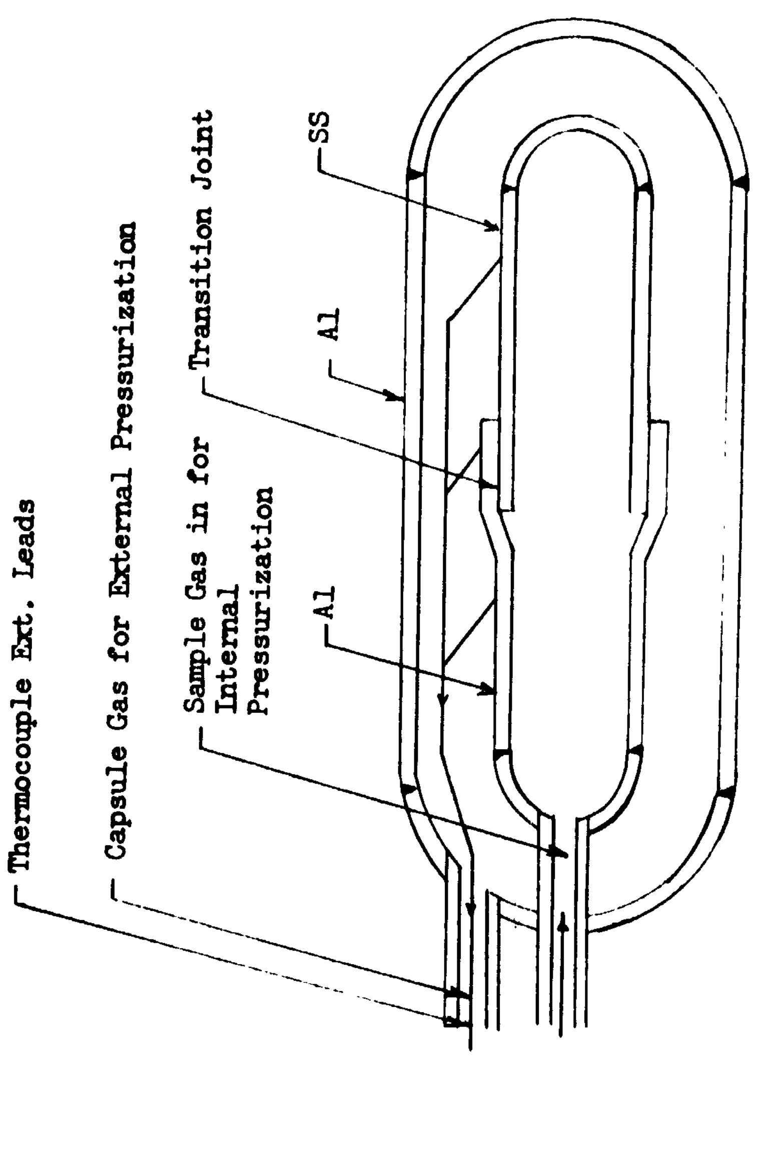


Figure B.2 - Sketch of Aluminum - Stainless Steel Test Fixture

The capsule assemblies shall be fabricated in accordance with this specification, the drawings and WANL Process Specification 294506. The vendor shall submit to the Contracting Officer for approval six (6) copies of any fabrication details, ship and erection drawings of the in-pile capsule when particular details are not shown on the drawings or specified. In addition, any deviations from specifications, drawings, or code practices must be submitted to the Contracting Officer for approval prior to proceeding with such deviations. The approval of drawings or deviations does not relieve the vendor from any responsibility for error therein or from any obligations under the contract.

Prior to fabrication, the vendor shall prepare a detailed fabrication schedule of the subassemblies and submit it to the Contracting Officer for approval. The purpose of this schedule shall be to insure that every component, weld joint, brazed joint, and mechanical joint of the capsule shall successfully pass all tests as hereinafter specified in the proper sequence prior to becoming inaccessible.

Welding and Brazing - All welding and brazing procedures shall be submitted to the Contracting Officer for approval. No welding shall be performed prior to approval of the procedure. Approval by the Contracting Officer will be for general conformance to the special requirements of the work and will in no way relieve the vendor of his responsibility to produce satisfactory work. Welding shall be in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section VIII; Unfired Pressure Vessels, Section IX; Welding Qualifications and Piping Code ASA B 31.1 and as hereinafter specified. Pressure containment welds shall be Type 1, dye-penetrant inspected and 100 per cent radiographed.

All welding and brazing shall be performed in a manner so as to maintain the dimensions and tolerances indicated on the drawings and as outlined in WANL Process Specification 294506.

Welding of Stainless Steel - Wherever possible, welding shall be performed by manual inert gas shielded metal-arc (tungsten electrode) process with consumable insert; otherwise, shielded metal-arc process shall be used with butt welded joints.

a. Electrodes shall conform with ASTM A 298, Type E 308 ELC.

b. Consumable inserts shall be EB type as developed by Electric Boat Corporation or approved equal. The consumable insert shall deposit undiluted solid metal that shall contain a minimum of 6 per cent delta ferrite in the chrome-nickel equivalents.

c. Only argon gas shall be used for shielding and purging; purity shall be 99.8 per cent.

d. All surfaces to be welded at least 2 inches each side of the joint shall be free of oxides, scale, oil, grease, cutting fluids and other impurities.

e. Welding shall be performed in the flat position (horizontal rolled) to the maximum extent possible.

f. All wire brushing shall be performed using stainless steel wire brushed.

g. All grinding shall be performed using rubber or resin bonded aluminum oxide or silicon carbide wheels.

h. Preheat shall not be employed except when the base metal is below 60°F. Preheating shall raise the temperature to within range of 60°F to 85°F.

i. Jigs, fixtures and clamps shall be employed to the maximum extent practical to establish and maintain alignment of the base metal and joint dimensions. Alignment shall be carefully controlled at the time of tacking so as to achieve the dimensional tolerances required.

j. The consumable insert formed ring with an overlap shall be sprung into the smaller of the two pipe ends; small tack weld shall be made between the ring and the one pipe end at about 4 inches spacing around half the circumference. The ring overlap shall be carefully trimmed off so that the gap does not exceed 1/32 inch. The remainder of the circumference shall then be tack welded, and the second pipe end is then fitted over the ring. Tack welds joining both pipe ends and the insert are finally made every inch at the location of the original tack welds and between them at equally spaced intervals. The ends of the pipe shall be prepared for the consumable insert.

k. The inside of the pipe during final tacking and fusion welding of the consumable insert shall be purged with argon gas to assure complete freedom of oxidation of the inside surface of the fused insert.

l. The weld shall be thoroughly wire brushed to remove surface oxide. Peening shall not be employed at any stage of welding.

m. The bead contour inside the pipe shall be a slight reinforcement bead uniformly and smoothly blended into the parent metal surface.

n. Weldments shall not be subjected to any intermediate or post-weld heat treatment.

<u>Welding and Brazing of Aluminum</u>

a. Aluminum shall be welded in accordance with the requirements of the Alcoa manual on <u>Inert Gas Shielding Type Welding of Aluminum</u>.

b. Aluminum shall be brazed in accordance with the requirements of the Alcoa manual on Brazing Aluminum.

c. All brazed joints shall develop the full strength of thinnest aluminum section adjacent to the joint.

d. The brazed aluminum to stainless transition joint shall be a "Bi-Braze" transition joint as manufactured by the Bi-Braze Corporation and will be furnished by the Contracting Officer.

e. All aluminum components in the completed assembly shall be T6 temper throughout except as noted on the drawings.

Finish of Aluminum

After final surface finishing operations, the entire exterior and interior aluminum surface of the in-pile section of the capsule shall be coated with finish as indicated on drawings. The coating shall be applied by the Anodize Treatment Process as outlined in MIL Spec 2470 EAMS.

B.3 DELIVERY OF CAPSULE ASSEMBLY

Packing - The vendors shall use every precaution in the crating and packing of the capsule assembly to prevent damage during shipping and unloading. The assembly shall be uniformly supported for its full length to prevent damage and distortion. All open ends shall be sealed by plastic covers and wood protection blocks. The entire capsule shall be covered with a polyethylene bag and sealed.

Unpacking - The vendor's engineer shall supervise the unpacking of the capsule assembly at the installation site with a representative of the Contracting Officer present.

APPENDIX C

EQUIPMENT LIST

C.1 Capsule

C.2 S.S. Valves

C.3 Piping and Components

C.4 In-Reactor Materials

C.1 CAPSULE

Materials for the capsule ensemble are listed in the following drawings:

709J928
709J929
709J930
709J931
387D518
566F386
566F387
566F391

C.2 S.S. VALVES

Valve No. Size	Valve Name	Body Material	Type	Mark No.	Operation	Test/Press. Temp.	Design Press/Temp.	Operating Press/Temp.	End Preparation	Manuf. Name & Fig. No.	Dwg. No.	Packing No. & Packing Manuf	Purchase Order No.
PC-V1-2"	Capsule Inlet	304 SS	Globe		Reach Rod	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Socket Weld	Aloyco 314			16980
PC-V2-2"	Capsule Outlet	304 SS	Globe		Reach Rod	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Socket Weld	Aloyco 314			16980
PC-V4-3"	Capsule Bypass	304 SS	Gate		Reach Rod	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Butt Weld	Aloyco 314			16980
PC-V3-2"	System Ck.	304 SS	Swing Ck.		Fluid	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Socket Weld	Pacific-1102			16979
P-V1-1½"	Capsule Purge	304 SS	Globe		Reach Rod	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Socket Weld	Pacific-702			16982
VD-V1-1½"	Capsule Drain	304 SS	Globe		Reach Rod	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Socket Weld	Pacific-702			16982
EC-V2-1½"	Emeg. Cooling Block	304 SS	Globe		Reach Rod	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Socket Weld	Pacific-702			16982
VD-V2-1"	HT-1 Vent	304 SS	Globe		Reach Rod	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Socket Weld	Pacific-702			16983
VD-V3-1"	Capsule Vent	304 SS	Globe		Reach Rod	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Socket Weld	Pacific-702			16983
EC-V1-1½"	Emerg. Cooling Block	304 SS	Swing Ck.		Fluid	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Socket Weld	Pacific-1102			16981
PC-1V2-½"	Water Relief	304 SS	Relief		Fluid	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Flanged	Mipco-1 SS			16985
PC-1V1-¼"	Instr. Outlet	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
PC-1V3-¼"	Instr. Bypass	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
PC-1V5-¼"	Instr. Test	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
PC-1V4-¼"	Instr. Outlet Test	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
PC-1V7-¼"	Instr. Inlet	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
PC-1V6-¼"	Instr. Outlet	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
PC-1V8-¼"	Instr. Bypass	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F					Storeroom
PC-1V10-¼"	Instr. Test Inlet	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
PC-1V9-¼"	Instr. Test Outlet	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
PC-1V12-¼"	Instr. Isolation	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
PC-1V11-¼"	Instr. Vent	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
PC-1V2-¼"	Instr. Outlet	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
SA-V1-¼"	Helium	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
SA-V2-¼"	Helium	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
SA-V3-¼"	Helium	304 SS	Needle		Manual	240 Psig/ 70°F	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
SA-V4-¼"	Helium	304 SS	Needle		Manual	240 Psig/	160 Psig/ 300°F	140 Psig/ 160°F	Tubing	Imperial			Storeroom
PB-15V33-1½	HT-1 Purge	304 SS	Gate		PB Reach Rod				Flanged	Powell			Plum Brook

C.2 S.S. VALVES (cont'd)

Valve No. Size	Valve Name	Body Material	Type	Mark No.	Operation	Test/Press. Temp.	Design Press/Temp.	Operating Press/Temp.	End Preparation	Manuf. Name & Fig. No.	Dwg. No.	Packing No. & Packing Manuf.	Purchase Order No.
PB-20V67-1½"	HT-1 Drain	304 SS	Globe		PB Reach Rod				Flanged	Powell			Plum Brook
PB-29V13-1½"	System Outlet	304 SS	Gate		PB Reach Rod				Flanged	Powell			Plum Brook
PB-29V61-1½"	System Isolation	304 SS	Ball		PB Reach Rod				Flanged	Powell			Plum Brook
PB-29V01-2"	System Isolation	304 SS	Gate		PB Reach Rod				Flanged	Powell			Plum Brook
PB-15V31-1½"	DW Block Quad. A	304 SS	Gate		PB Reach Rod				Flanged	Powell			Plum Brook
PB-15V34-1½"	Quad. A DW Spare	304 SS	Gate		PB Reach Rod				Flanged	Powell			Plum Brook
PB-15V32-1½"	Quad. A DW Check	304 SS	Check		PB Reach Rod				Flanged	Powell			Plum Brook
PB-20V68-1½"	DW Block	304 SS	Globe		PB Reach Rod				Flanged	Powell			Plum Brook
PB-15V40-1½"	DW	304 SS	Gate		PB Reach Rod				Flanged	Powell			Plum Brook

C.3 PIPING AND COMPONENTS

WANL MARK NUMBER	PBRF MARK NUMBER	IDENTIFICATION NAME	TYPE SCH. or POUNDS	MATERIAL TYPE	PART NO. or IDENT. NO.	SUPPLIER or VENDOR	PURCHASE ORDER NO.	END PREP.	SIZE
709J932		Reducer	10	304L	25010	Ladish Co., Wis.	16972	Butt Weld	3" x 2"
709J932		Reducer	10	304L	25010	Ladish Co., Wis.	16972	Butt Weld	2" x 1"
709J932		Reducing Tee	10	304L	24110	Ladish Co., Wis.	16972	Butt Weld	2" x 1½"
709J932		Tee	10	304L	24010	Ladish Co., Wis.	16972	Butt Weld	3"
709J932		Tee	10	304L	24010	Ladish Co., Wis.	16972	Butt Weld	1½"
709J932		Elbow 45°	10	304L	20110	Ladish Co., Wis.	16972	Butt Weld	3"
709J932		Elbow 45°	10	304L	20101	Ladish Co., Wis.	16972	Butt Weld	1½"
709J932		Elbow 45°	10	304L	20101	Ladish Co., Wis.	16972	Butt Weld	2"
709J932		Elbow 90°	10	304L	20010	Ladish Co., Wis.	16972	Butt Weld	3"
709J932		Elbow 90°	10	304L	20010	Ladish Co., Wis.	16972	Butt Weld	1½"
709J932		Elbow 90°	10	304L	20010	Ladish Co., Wis.	16972	Butt Weld	2"
709J932		Flange	150#	304L	12015	Ladish Co., Wis.	38459	Slip On	3"
709J932		Flange	150#	304L	12015	Ladish Co., Wis.	38459	Slip On	2"
709J932		Flange	150#	304L	12015	Ladish Co., Wis.	38459	Slip On	1½"
709J932		Orifice Flange	300#	304L	0-31	Ladish Co., Wis.	38459	Slip On	3"
709J932		Pipe	150#	304L		Williams, Pgh.	38454		3"
709J932		Pipe	150#	304L		Williams, Pgh.	38454		1½"
709J932		Pipe	150#	304L		Williams, Pgh.	38454		2"
709J932		Flex. Gasket	150#	304	CG-1G	McJunkin, Leetsdale, Pa.	16988		2"
709J932		Flex. Gasket	150#	304	CG-1F	McJunkin, Leetsdale, Pa.	16988		1½"
709J932		Flex. Gasket	150# & 300#	304	CG-1J	McJunkin, Leetsdale, Pa.	16988		3"
709J932		Thredolet	150#	304		Williams, Pgh.	38456		3" Pipe
709J932		Thredolet	150#	304		Williams, Pgh.	38456		3" Pipe
709J932		Thredolet	150#	304		Williams, Pgh.	38456		2" Pipe
709J932		S.S. Tubing		304		Williams, Pgh.	16986		½" x .049 Wall
709J932		Mounting Plate		6061-T Al.	576F013602	Williams, Pgh.			½" 14" x 84"
709J932		Orifice Plate			576F013H01	WANL Machine Shop			
709J932		Male Conn.			400-1-2W-316	-		Butt Weld	
609J932		Cap	10		25510	Ladish Co., Wis.		Butt Weld	1"
709J932		Flex Hose	150#	316		Cypher, Pgh.	16984	Flanged	28' 2"
709J932		Flex Hose	150#	316		Cypher, Pgh.	16984	Flanged	30' 2"
709J932		Flex Hose	150#	316		Cypher, Pgh.	16984	¼ Female Ftgs.	¼"

C.4 IN-REACTOR MATERIALS

A spectrochemical analysis was made on a sample of the 6061-T6 aluminum tube used for the in-pile section of W-2 Water Cooled In-Pile Capsule. The weight percentage breakdown of the materials was found to be as follows:

Material	Weight %
Aluminum	97.4 ±.2
Iron	.372
Manganese	.068
Copper	.252
Chromium	.217
Zinc	.1
Titanium	.02
Nickel	.03
Silicon	.59
Magnesium	.91

APPENDIX D

INSTRUMENT LIST

Table D.1

INSTRUMENT LIST

Designation		Instrument	Parameter(s) Measured	Range	Function	Mfg. and Model No.
IX*	FX1**	Transmitter D/P	Inlet Flow	0-50" of H_2O input 1-5 ma output		L & N, M-Line No. 177098
OX	FX2	Transmitter D/P	Outlet Flow	0-50" of H_2O input 1-5 ma output		L & N, M-Line No. 177098
FR	FR1-1 & 2	2-Pen Recorder	System Flow	0-100 gpm	Record	Speedomax, Type M No. 177090
M3	FS1-b	2-Point Contact Meter	Inlet Flow	0-5 ma	Alarm	API Model No. 502-L
M4	FS2-b	2-Point Contact Meter	Outlet Flow	0-5 ma	Alarm	API Mocel No. 502-L
P1	-	Power Supply	Inlet Flow	24 v.d.c.	Supply Transmitter Power	L & N, M-Line No. 099015
P2	-	Power Supply	Outlet Flow	24 v.d.c.	Supply Transmitter Power	L & N, M-Line No. 099015
FS-3 & FS-4	FS-3 & FS-4	Monitor Switch	Inlet Lo Lo Flow	1-5 ma	Alarm & Scram	Minn. Honeywell No. 913 130-110
FS-5 & FS-6	FS-5 & FS-6	Monitor Switch	Outlet Lo Lo Flow	1-5 ma	Alarm & Scram	Minn. Honeywell No. 913 130-110
-	PI-1	Pressure Indicator Gage	System Pressure	0-200 psi	Local Gage	U. S. Gage Co.
PX	PX1	Transmitter	System Pressure	0-300 psi input 1-5 ma output		L & N, M-Line No. 177097

Table D.1 (Cont'd)

INSTRUMENT LIST

Designation		Instrument	Parameter(s) Measured	Range	Function	Mfg. and Model No.
M1	PS-1b	2-Point Contact Meter	System Pressure	0-5 ma	Alarm	API Model No. 502-L
P3	-	Power Supply	System Pressure	24 v.d.c.	Supply Transmitter Power	L & N, M-Line No. 099015
PT	PR-1/TR-2	2-Pen Recorder	Pressure/Experiment Temperature	0-300 psi/0-300°F	Record	Speedomax, Type M No. 177090
M2	TS-2a	2-Point Contact Meter	Experiment High Temperature	0-5 ma	Alarm	API Model No. 502-L
TX	TX-2	Transmitter	Experiment Temperature	0-7.32 mv input 1-5 ma output	EMF/I Converter	L & N, M-Line No. 177093
TR	TR-1	Multipoint Recorder	System & Experiment Temperature	60-260°F/24-point capability	Record & Alarm	Daystrom Model 6704
SA	AA	Annunciator	Flow/Pressure/ Temperature	8 Channel	Audible-Visible Alarm	Scam, S-Line No. ACS-9

* Code number used in WANL Dwg. No.
**Code number used in WANL Dwg. No. 566F394.

APPENDIX E

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Appendix B

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